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A RESEARCH STUDY TO DEFINITIZE A BIO-ISOLATOR SUIT SYSTEM (BISS)

ORAL PRESENTATION REPORT NO. 1

GENERAL ELECTRIC

RE-ENTRY SYSTEMS DEPARTMENT

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PREPARED FOR

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SECTION 1

SUMMARY

1. SUMMARY

This is the first Oral.Presentation report on Contract NAS1-6537. It covers the program accomplishments for the first four months and the status at the end of the period, and includes the fourth monthly technical progress report. The data contained herein is a documentation and expansion of the materials presented and discussed at the Oral Presentation held at the General Electric Company, Philadelphia on 29 November 1966.

The highlights of the activity and accomplishments on each of the five program tasks are summarized below.

TASK I SYSTEM CRITERIA

The System Criteria document is completed and included herein as Appendix A.

TASK II CONCEPT DEVELOPMENT

The concept of the BISS system has developed to the point of defining requirements for, and interrelationships between, virtually all elements of the BISS system. This effort has been carried to the point where it is now possible to define a Phase II mock-up for task V with confidence that it will be a reasonable simulation of the ultimate BISS system to be developed.

TASK III INTEGRATED TEST PLAN

The integrated test plan has been completed and submitted under separate cover to NASA/LRC.

TASK IV MATERIALS ANALYSIS

The primary materials analysis effort has been in selection of candidate materials, data search on these materials, limited physical testing, fungus testing, and extensive preparatory effort for the testing of permeability of materials to microorganisms.

TASK V MOCK-UP TEST PROGRAM

The Phase I mock-up tests are essentially complete. During the period, the mock-up was designed; fabricated; and subjected to component, subsystem, and system tests. Preparations for the Phase II mock-up test program are under-way.

No technical or administrative problems have occurred during the period covered by this report and none are foreseen.

SECTION 2

PROGRAM TASKS

2. PROGRAM TASKS

2.1 System Criteria

The System Criteria for the BISS have been defined to provide guidelines for the BISS Concept Development, Task 2. The Criteria definition covers the following nine areas:

1. Configuration
2. Bio-Integrity
3. Technician Environment
4. Technician Safety
5. Human Factors
6. Hygiene
7. Equipment Environment
8. BISS Endurance
9. Sterile Maintenance

Appendix A hereto presents the first issue of the Bio-Isolator Suit System Criteria. This document has been issued as an internal GE program engineering directive. Second and third tier criteria will be documented in internal memorandum until and unless incorporated in the specifications to be prepared under Task 2 is appropriate.

This task is essentially completed; no further effort will be expended on System Criteria unless results from the other tasks indicate a need to revise or expand the criteria document.

2-2 TASK II CONCEPT DEVELOPMENT

2-2.1 Suit and Tunnel and Hatch

A. Status of Concept

The basic requirement which the BISS must satisfy is to provide an absolute biological barrier between its wearer and a sterile environment, while allowing the wearer sufficient mobility, dexterity and visual field to execute spacecraft assembly and check-out operations in the sterile environment. Corollary requirements are for operator safety and comfort in the work environment.

To enhance confidence in the bio-integrity of the BISS, the requirement has been imposed for operation of the suit in a nominal overpressure environment of up to 4" of water acting inward on the suit. This overpressure condition is intended to combat the migration of microbes and bacteria across the suit barrier in the event of small punctures, tears or ruptures. From the standpoint of the suit wearer or operator, this overpressure condition increases the difficulty of entry and exit and is a potential impediment to comfort and endurance. For this reason, suit, tunnel and hatch design must strive to minimize any deleterious effects of the overpressure environment.

The development and evolution of the concepts for the BISS suit, tunnel and hatch are interrelated, but for the purposes of this report each will be treated separately. Basically, the suit is the BISS operator's protective envelope. The tunnel provides a means for permitting the operator to move about the sterilized chamber, and the hatch provides interfaces between the suit-tunnel combination, Assembly/Sterilizer and non-sterile environment. The operator's entry to and exit from the chamber will be through the BISS hatch assembly.

The BISS suit consists of an outer suit and an undersuit. The outer suit will be a multi-layer plastic laminate which will have attached to it relatively form-fitting gloves, semi-rigid boots (e.g. fireman's boots), and a fishbowl helmet and support harness (or yoke). Support rings will flank the elbows and thighs. Also, the outer suit will interface with the tunnel by means of a 100" circumference opening in the back of the suit.

The undersuit is presently conceived as being composed of a multi-layer undergarment which permits air circulation for body cooling and provides pressure relief to the operator. The undersuit provides two plates which will serve as attachment points for the communications system transducers. An interface is also provided between the undersuit and the life support subsystem plenum.

The present BISS tunnel concept is for a soft tunnel extending between the suit and the hatch assembly. This tunnel will be supported by an overhead boom. Two rings will be placed at the

suit end of the tunnel to keep it open for entry and exit.

The hatch assembly is currently conceived as a hard tube (called the reefing tube) which will provide a means of entry to and exit from the chamber, a hatch or door at the entrance to the tube, and associated support and reefing equipment. This tube will be like many watertight doors in shape; parallel sides with a semi-circular top and bottom. Very probably, the exterior portion of the reefing tube extending into the tunnel will be used to hold the reefed tunnel material when the tunnel is contracted, but this is contingent upon the further evaluation of existing reefing concepts, and perhaps the generation of other new reefing concepts.

B. Development of Concept

(1) Suit Subsystem

The first significant concept development effort was the performance of a hard versus soft suit trade-off. The following listing identifies the factors considered and the nature of the hard versus soft suit decision in each case.

Factors Considered	Favored Suit
. Weight	soft
. Size; fit	soft
. Mobility	soft
. Operational efficiency	soft
. Personal hygiene	hard/soft (equal)
. Entry-Exit mechanics	hard
. Leak proofing	soft
. Safety	hard
. Provision of life support and communications	hard/soft (equal)
. Sterilization cycle compatibility	hard/soft (equal)

The design decision which resulted from this trade-off was to develop a soft outer suit with a separate undergarment which will:

- Contain manifolding air distribution and exhaust.
- Act against overpressure effects of outer suit on operator.
- Act as a personal garment to promote good hygiene and to act as container for personal bacteria.
- Contain parts of the life support and communications equipment which would be subject to degradation or damage during chamber sterilization.
- Permit the use of the softest outer suit configuration compatible with outer suit requirements.

The outer suit was envisioned as an anthropometrically shaped envelope accommodating American males in the 30th through 80th percentiles in height and weight. This concept included a hard helmet and replaceable boots and gloves. Further, it was required that some type of communications be provided for the operator. Detailed treatment of the evaluation of each of the principal elements in the suit subsystem follows.

(a) Undersuit

One of the ramifications of a soft outer suit is that the overpressure condition tends to collapse the suit against the operator's body, inhibiting the circulation of cooling air. Thus, the idea was evolved of an independent undersuit which would channel cooling air and an outer suit which would be a bio-barrier between the operator and the sterile Assembly/Sterilizer chamber. Early life-support trade-offs, in conjunction with the foregoing suit subsystem evaluation, suggested a three layer garment: a cotton material to interface with the wearer's skin; an open pore foam which would compress under the overpressure, but which would still permit air circulation; and a third layer which would seal the outer face of the foam, thereby permitting channeling the flow of the cooling air.

The undersuit was conceived as a garment tailored for the individual operator with all three layers bonded together. The difficulty of bonding the cotton undergarment separately from the rest of the undersuit, resulted in the further modification of the undersuit concept. This modification was to use separate long cotton underwear under a two layer (foam and neoprene) basic undersuit.

Additional development of this concept based on Phase I mock-up experience has indicated that the neoprene outer layer of the undersuit should be replaced by a thin,

non-friction producing type of material. It was found that the neoprene grabbed against the outer suit material and reduced the ease of operator entry and exit. Similarly, it was concluded that a means was required to reduce friction between the inner layer of the foam and the operator's underwear. This will be accomplished by bonding a thin, highly-porous, low-friction material to the inner surface of the foam.

Therefore, the current undersuit concept is for the use of separate long underwear and a three-layer (bonded) garment which provides for overpressure relief and air circulation. The exploitation of this air circulation capability to provide operator cooling is discussed in Section 2-2.2 of this report dealing with the BISS Life Support System. Another undersuit feature will be two hard points located on the upper, front portion of the undersuit which will serve as mounting points for the communications system transducers. Though placement of these items in the helmet might simplify undersuit design, the present approach eliminates the need for subjecting the communications system transducers to the rigors of the sterilization treatment temperature.

(b) Outer Suit

The outer suit is envisioned as a shell employing bonded boots and gloves which are detachable only for replacement. The fishbowl helmet is, in the broadest sense also a part of the outer suit. The neck of the outer suit is permanently sealed to the fishbowl. However, since the requirements for the boots, gloves, and helmet are intrinsically different from the rest of the outer suit, the development of the concepts for these items is treated separately in this report.

The choice of an outer suit material is in process. The choice of an optimum material which can withstand the rigors of sterilization, provide a bio-barrier between the suit wearer and the chamber environment, and not inhibit operator motion due to weight or rigidity is the goal of this effort. Currently, a number of multi-layer laminated plastics are being subjected to competitive evaluation. The suit material trade-off will be performed by materials literature search, testing, and microbiological studies discussed in Section 2.4 of this report.

The concept of outer suit sizing has undergone modification. It was found during the Phase I mock-up study that imprecise sizing of the suit impeded the operator in entry and exit under pressure because of the folding and collapse of excess suit material. Therefore, careful analysis of

sizing the outer suit to accommodate the 30th - 80th percentile (in height and weight) American male must be made. It is possible that a more homogeneously sized operator population will be required for a given outer suit.

In addition to the possibility of making the outer suit fit more precise, the mock-up study has indicated the need for two stiffening rings in both the arms and legs of the suit. These rings flank the elbows and thighs respectively and in no way hamper operator mobility. In conjunction with two large rings located at the suit end of the tunnel, and a donning rack which supports the suit in a proper donning attitude at the end of the hatch tube, the arm and leg rings greatly facilitate operator entry into the suit under the overpressure environment. The rings accomplish this by creating discernable openings, appropriately positioned, at which the operator can aim during the entry process. These features also aid in exit from the suit by reducing the amount of suit collapse on the limbs.

The openings in the back of the suit which interfaces with the tunnel will be 100" in circumference. This value has been used in the mock-up and has been proved to be adequate for operator entry and exit.

(c) Boots

The first concept for the BISS boots was to use a loose fitting envelope of suit material with a durable traction surface on the bottom. This shell would have merely covered normal work shoes which the subject would wear in the suit. Foot support and toe protection were to be provided by the operator's work shoes. The concept has now developed to that of a relatively rigid boot with built in foot protection and support. Since the boots are not changeable from individual to individual, personal inner socks or slippers will be required for each operator to help maintain hygiene and to accommodate a range of foot sizes.

(d) Gloves

The gloves of the BISS outer suit are conceived to be soft and highly flexible to promote a maximum of finger and hand dexterity. The gloves cannot be form-fitting, e.g. surgeon's gloves, because of the difficulty of donning and doffing them and the puncture or rupture hazard to such a glove. However, gloves will be sized to promote a minimum of extra space beyond that needed to accommodate the selected user population. An inner glove of soft cotton is recommended for the purposes of hygiene, to minimize perspiration buildup, and to provide some degree of sizing adjustment.

(e) Helmet

The earliest concept of a helmet for the BIBS suit was for a clear, supported helmet. Experimentation with a cylindrical and an Apollo-type helmet has strongly suggested the appropriateness of large "fish-bowl" or "bubble" type helmet. This is necessary since the helmet will not move with the operator's head and contouring of the helmet in a conventional manner would interfere with the operator's head movement. A cotton cap will be worn by each operator to avoid smearing the helmet with hair oils, etc. The optical qualities and mechanical properties, e.g. shock and heat resistance, of various candidate helmet materials are under investigation.

Unlike pressure suit helmets which derive physical support from the suit pressure, a means must be provided to support the helmet in the overpressure environment. This will be done by the use of a molded shoulder yoke with elastic bands which go under the wearer's armpits as shown in Figure 1. This yoke will be permanently affixed to the helmet and will therefore be a part of the outer suit. The mock-up study has demonstrated the feasibility of the use of such a support mechanism.

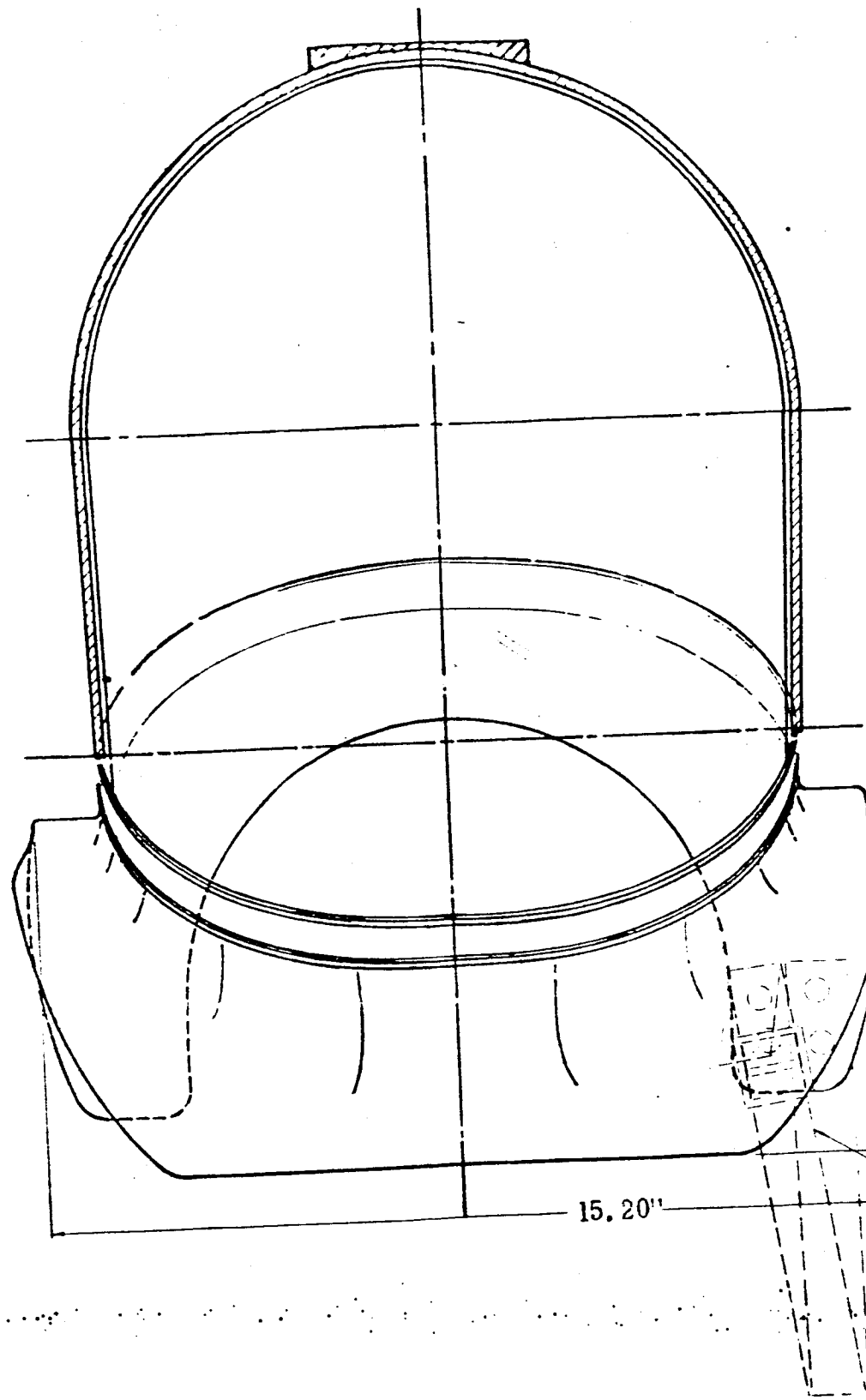
(2) Tunnel Subsystem

The hard versus soft tunnel comparative analysis was conducted in conjunction with the hard versus soft suit analyses. The listing below indicates the factors considered and the nature of the decision in each case.

TABLE I - TUNNEL TRADE-OFF

Factors Considered	Favored Type of Tunnel
Weight	soft
Size (diameter)	soft
Operator mobility	soft
Operational efficiency	soft
Entry-exit mechanics	hard
Sterilization cycle compatibility	hard/soft (equal)
Provision of life support and communications	hard/soft (equal)

As a result of the foregoing analysis, the tunnel was conceived as being made of a relatively soft fabric identical, or nearly identical, in composition to that of the outer suit. This tunnel bridges the gap between the outer suit containing the operator and the reefing tube through which the operator enters into or exits from the outer suit. The tunnel carries the life support



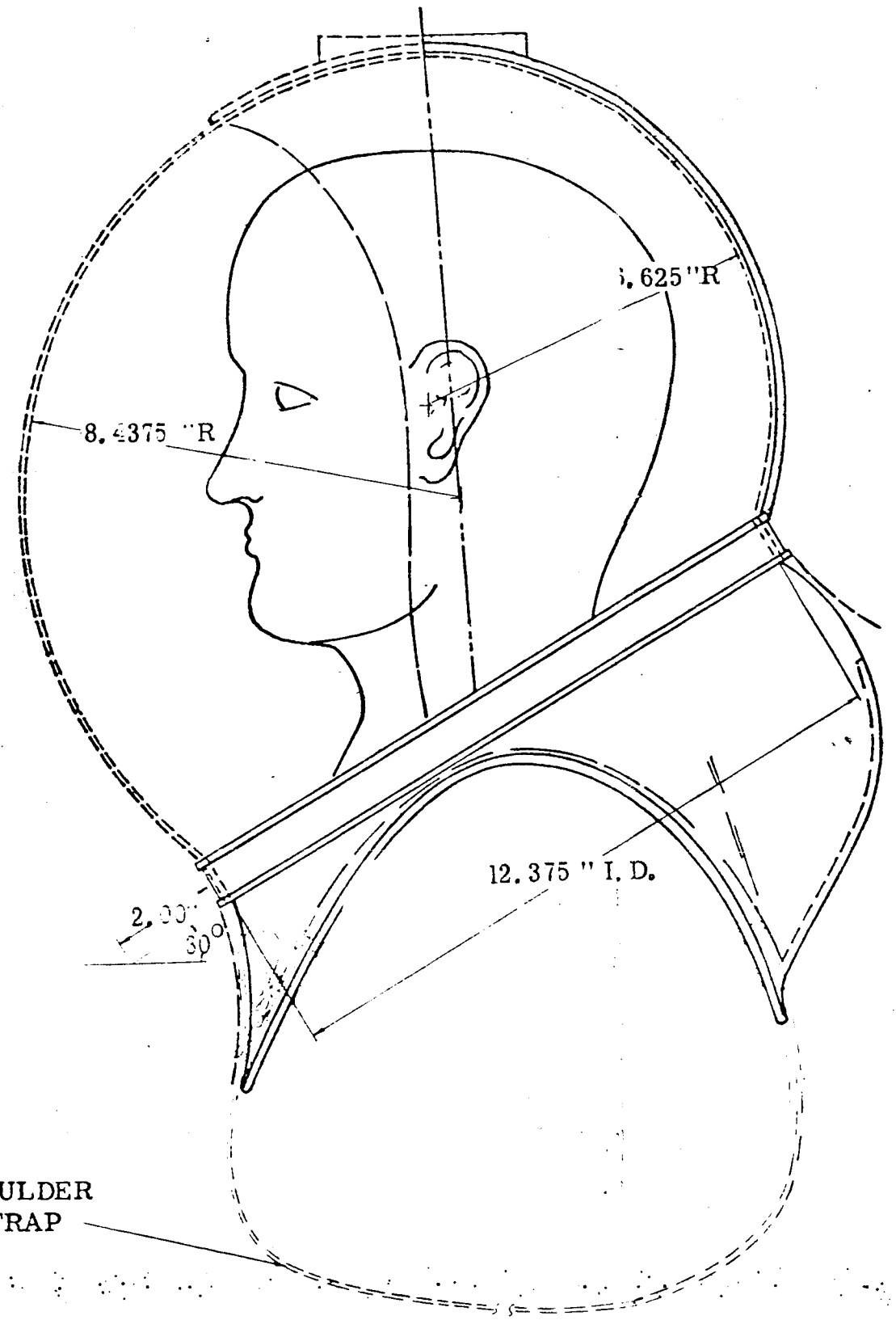


FIGURE 1

HELMET-YOKE
ASSEMBLY CONCEPT

and communication lines to the operator and is itself supported by stringers to an overhead boom. As the operator moves about in the chamber, the boom supports the tunnel and accommodates three dimensional movement, thus protecting the tunnel from abrasion and permitting it to remain collapsed under the overpressure. The collapse of the tunnel is necessary to prevent the operator from being subjected to an axial force of approximately 30 lb per inch of water pressure. Two rings are required at the suit end of the tunnel to hold open the back of the suit to facilitate operator entry and exit.

Since reefing of the tunnel is crucial to entry and exit, the reefing concept has been given substantial thought and evaluation. Early mock-up tests indicated that pulling the tunnel through the hard reefing tube and attempting to lap it back over the hard tube outside the chamber was not feasible as a means of reefing. The in-chamber overpressure caused the tunnel to balloon out through the tube and prevented manual reefing operations. Subsequent in-chamber manual reefing (on the in-chamber projection of the reefing tube) under two inches of water overpressure has indicated that the amount of force necessary to overcome the pressure on the fabric is not excessive for manual reefing. However, because of the erratic behavior of the flexible tunnel material under the overpressure environment, it is evident that a device of substantial sophistication will be required to mechanically reef the tunnel. One design approach which is under consideration involves a series of velcro-covered wheels, located around the perimeter of the reefing tube, acting on strips of velcro attached to the exterior of the tunnel. Currently, an extensive effort is being initiated to develop alternate mechanical reefing schemes which can be evaluated during the remainder of the program.

The concept of a hard tube and its attendant reefing method is dictated by the desire to utilize an antechamber only for maintenance and emergency rescue. The antechamber's primary use will be for removing, replacing, or repairing the BISS suit and tunnel and its secondary use will be for emergency rescue work, as required.

It is intended that the ordinary, routine entry to and exit from the BISS suit be made through the hatch, under reefed tunnel conditions, without resorting to use of the antechamber.

(3) Hatch Subsystem

The function of the hatch subsystem is to provide an interface between the BISS suit-tunnel combination, the sterile Assembly/Sterilizer chamber and the non-sterile areas outside. Initially, the hatch assembly was conceived of as a circular tube of approximately 30" I.D. running from the outside of the chamber and extending far enough into the chamber to permit reefing of the tunnel on it. This concept has evolved into that of a reefing tube having parallel sides and a semi-circular top and bottom with a hatch or door at the entrance. This shape promotes the ease of passage of a sitting

operator through the reefing tube. The concept of reefing the soft tunnel on the outside of the reefing tube, as well as the final geometry of this tube, is dependent upon further development of the reefing concept.

Another facet of the hatch concept is the use of a large, domed piston which is inserted in the hatch after the operator has gained entry to the chamber. This piston prevents the soft tunnel material from collapsing back into the reefing tube and thereby facilitates reefing. Openings for life support and communication lines have to be provided in the piston. The feasibility of this concept has been demonstrated in the mock-up study. Its application in the final system is dependent upon final reefing system definition and selection.

The ultimate BISS hatch assembly must also interface with an independently sterilizable antechamber which will be used for suit maintenance and emergency-rescue operations. This antechamber will be located between the non-sterile environment and the chamber. Further discussion of this antechamber will be found in Sections 2-2.5 and 2-2.7.

2-2.2 Life Support and Monitoring

A. Status of Concept

The hardware employed in the present BISS life support subsystem concept consists of an air conditioning unit, air cooled undersuit, air distribution ducts and hoses, distribution and exhaust plenums and an exhaust blower. The air conditioning unit supplies cool, dry air which is delivered to the suit distribution plenum by flexible ducting. From the plenum, cooling and breathing air is directed to the suit's gloves, boots and helmet by means of flexible tubing. The air is then drawn into the undersuit's open-pore polyurethane foam liner, which has openings at the extremities, by the action of the exhaust blower. The continous, low resistance flow path offered by the foam provides uniform body cooling. The output of the air conditioner and the exhaust blowers can be adjusted by means of variable auto-transformers to maintain the suit pressure at any desired level. Humidity control is effected by injecting water mist into the cool, dry air leaving the air conditioner. Humidity in the suit is maintained at 40 - 50% by manual adjustment of the air flow and water injection rates.

Air flow rates are monitored by passing inlet and exhaust air through rotometers. Thermocouples are imbedded in the foam of the undersuit to measure suit air temperatures. Suit humidity is monitored by means of an electrical hygrometer probe in the exhaust plenum.

Principal future life support activities will be evaluation of the mock-up test data, preparation of procurement specifications for the Phase II hardware, procurement of the Phase II life support subsystem and evaluation of the subsystem in conjunction with suit and tunnel tests.

B. Development of Concept

The life support subsystem is required to provide a healthful, comfortable environment for the technician in the suit while he performs "light" manual labor. To do this, it must control the temperature, humidity and to some extent, suit pressure. After a general survey of life support literature, the following values were established as subsystem design parameters* to be validated by tests;

(a) Heat removal capacity - 1600 BTUH

(b) Helmet air flow rate - 2.5 CFM

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* These values were abstracted from "bioenergetics of Space Suits For Lunar Exploration," by E.M. Roth, M.D., 1966.(NASA SP 84)

(c) Moisture removal - 1 liter/hour maximum

(d) Temperature of suit atmosphere - 77°F

(e) Humidity of suit atmosphere - 40% r.h.

In developing a solution to the temperature and moisture control problem, a trade-off of three classes of cooling systems was made. The three classes of systems which were evaluated were "open" and "closed" systems with air as the cooling fluid and a "closed" system with a liquid as the cooling fluid. In this context an open system is one in which there is direct contact between the cooling fluid and the wearer's body. In the closed system, a membrane is interposed between the cooling fluid and the wearer's body. For the air-cooled system, this membrane was to be semipermeable and not susceptible to blockage caused by overpressure compression, thereby allowing the passage of moisture through it. The membrane for the liquid cooled suit was to be impermeable to the cooling fluid.

(1) Trade-Off

Air-Cooled "Open" versus Air-Cooled "Closed" versus Liquid Cooling Temperature and Moisture Control Systems.

TABLE II - BASIC COOLING SYSTEM TRADE-OFF

AIR-COOLED "OPEN" SYSTEM

ADVANTAGES	DISADVANTAGES
(a) Fair heat exchange medium.	(a) Cooling air distribution may be less uniform than for a "closed" system.
(b) Non-toxic medium, leakage poses no problem.	(b) Large supply and exhaust ducts required.
(c) Excellent mositure control possible.	(c) Moisture vapor loss in supply ducting would probably vary with ambient conditions, thereby making humidity control difficult.
(d) Ducting in suit is minimized.	
(e) Light weight medium and ducting.	

TABLE II - Continued

ADVANTAGES	DISADVANTAGES
(f) Nominal amount of development work required.	
(g) Complexity of supply and control devices is no greater than that of similar industrial devices of proven reliability.	

AIR-COOLED "CLOSED" SYSTEM

ADVANTAGES	DISADVANTAGES
(a) Most of the advantages of the "open" system would apply since the heat exchange medium is the same.	(a) Additional complexity, weight and cost are added to the undersuit by the addition of the membranous distribution ducting.
(b) Uniform distribution of the coolant under an overpressure environment.	(b) Supply and exhaust ducting problems are the same as for the "open" system.
(c) Several suitable membranes are available.	(c) Location and sizing of the distribution ducting would require considerable effort.

LIQUID COOLING* WITH DESICCANT CARTRIDGES FOR MOISTURE CONTROL

(a) A simple system using water as the heat exchange medium is available (B. Welson, Apollo-type system).	(a) Suitably locating the desiccant cartridge within the suit might prove difficult.

*NOTE Refrigeratant liquids other than water were not considered since no major advantage was apparent, while such difficulties as toxicity, high cost and chemical reaction with the undersuit and ducting could be foreseen.

TABLE II - Continued

ADVANTAGES	DISADVANTAGES
(b) More efficient heat exchange than with a gaseous medium.	(b) Independent liquid input and output and breathing air input and output lines are required.
(c) Supply and return lines would be smaller than needed for a gaseous medium.	(c) Humidity control under varying conditions of activity would be poor.
(d) Suitable desiccants are commercially available and cartridges or bags are reusable.	(d) Localized pressure of the cooling tubing can cause irritation.
	(e) Weight of liquid filled supply lines would be greater than larger gas filled lines.

Conclusions: It was concluded that conditioned air was the best cooling fluid, primarily because of its superior moisture control properties and the relative simplicity of related hardware development requirements. A further conclusion was to compromise with regard to the "open" or "closed" air system. The compromise was to use a permeable membrane to promote air flow under the overpressure environment, but not to completely seal the undersuit off as would be the case in a truly "closed" system. Openings were located at the wrists, ankles and neck of the undersuit, which serve as entry ports for input air which is pulled through the suit's continuous membrane and exhausted from a plenum worn on the operator's waist. Input air would be supplied to the wearer's extremities by means of separate ducting located on the exterior of the undersuit. It was further decided that the readily-available water cooled suit of B. Welson, Inc. should be empirically compared with the air-cooled suit to be developed by G. E.

Additional lower-level trade-offs were required to support the system level trade-offs. The trade-offs performed were concerned with definition of a breathing and cooling air supply, the location of the cooling and breathing air distribution hardware in the suit system, and the method for chilling suit air. Advantages and disadvantages for each candidate problem solution are identified in the following trade-offs.

(2) Trade-Off

Self-Contained, Portable Back Pack versus Facility Mounted, Tubing Connected Life Support Systems.

TABLE III - AIR SUPPLY LOCATION TRADE-OFF

BACK-PACK

ADVANTAGES	DISADVANTAGES
(a) Requires no supply ducting.	(a) An exhaust hose would still be required.
(b) Accidental blockage of the tunnel would not create a dangerous condition for the subject.	(b) A breathing air supply adequate for a 4-hour shift would be too heavy to carry about and periodic recharging of the supply bottles would be time consuming.
	(c) Carrying sufficient air to provide cooling to other than the facial areas would be prohibitive due to the size and weight of the air bottles
	(d) The back-pack would increase the physical burden borne by the subject and tend to induce fatigue.
	(e) The presence of high pressure gas in the suit/tunnel introduces a danger of overpressurizing the suit in the event of an accident, or in case the tunnel exhaust route were cut off.

FACILITY MOUNTED SYSTEM

(a) Size and weight of the cooling supply equipment would not have any effect on the load borne by the subject, so that high capacity equipment could be used for long work periods.	(a) Life support ducting or hoses would be needed for both input and exhaust air. These would reduce the mobility of the subject slightly and interfere with tunnel reefing.

ADVANTAGES	DISADVANTAGES
(b) Capabilities for emergency air or oxygen, for other than a supply line blockage condition, could be incorporated into the system with no effect on the suit/tunnel design. Redundant systems could be incorporated for increased reliability.	(b) Accidental blockage of the tunnel could cut off the suit air and coolant supply, creating a potentially hazardous condition for the subject.
(c) A single life support system could suffice to supply more than one operator, so that the number of control and monitoring personnel and equipment could be minimized.	
(d) No high pressure gas would be required within the suit/tunnel for normal operational conditions.	

Conclusions: The facility mounted system was chosen because of endurance and reliability.

(3) Trade-Off

Mounting Cooling and Air Distribution Ducting on Unitary BISS Garment versus Mounting Cooling and Air Distribution Ducting on a Separate Undersuit.

TABLE IV - DUCTING TRADE-OFF
UNITARY GARMENT

ADVANTAGES	DISADVANTAGES
(a) Subject's entrance into and egress from the suit would be made easier.	(a) All components would have to meet the same sterilization requirements as the suit/tunnel.
	(b) Sizing adjustments required for individual operators would be difficult to make.

SEPARATE UNDERSUIT

ADVANTAGES	DISADVANTAGES
(a) The undersuit and life support equipment would not have to withstand sterilization temperatures.	(a) System complexity would be increased by using separate BISS undersuits and outer suits.
(b) Undersuit and support equipment could be tailored to fit each subject.	

Conclusion: The separate undersuit approach was chosen because it eliminates the need to develop sterilizable life support hardware and permits individual placement of life support equipment.

(4) Trade-Off

Use of a Conventional Compressor Type Cooling Unit versus an Escon Vortex Tube Heat Exchanger.

TABLE V - AIR COOLER TRADE-OFF
COMPRESSOR TYPE COOLER

ADVANTAGES	DISADVANTAGES
(a) Initial cost of an adequate unit (6000 BTUH) is relatively low.	(a) The unit is rather large - approximately 17 inches x 25 inches x 25 inches with plenum installed.
(b) Operation of the unit is understood and the design is well proven.	(b) A means is required to evaporate or drain off water condensed by the unit.
(c) Outlet air temperature can be easily controlled by thermostats.	
(d) Operation is quiet and reliability is excellent.	
(e) Air flow rate and temperature can be controlled independently; cooling does not depend upon air flow rate.	

ADVANTAGES	DISADVANTAGES
(f) A normal unit of this capacity can supply many times the 20 CFM maximum flow needed for suit operation.	
(g) Filtered outside air or room air can be used for both suit cooling and breathing air. No separate breathing air supply is required.	

VORTEX TUBE

ADVANTAGES	DISADVANTAGES
(a) The vortex tube assembly is simple and reliable, having only one moving part.	(a) If shop air is used for cooling, a separate helmet supply is required for breathing air.
(b) The vortex tube can be operated from shop air if it is available.	(b) Operation is quite noisy due to the high pressure air blast.
(c) No electric power is required for vortex tube operation if shop air is available.	(c) Adjustment of air temperatures directly affects flow rate and back pressure.
(d) The vortex tube is quite small and lightweight.	(d) Vortex tube capacity is limited to about 12 CFM which is marginal for this system.

Conclusions: The compressor type system was chosen because of its large capacity, silent operation, ease of temperature adjustment independent of flow rate, and the fact that a separate breathing air supply is not needed.

(5) Trade-Off Summary

Analytical trade-off studies have indicated that the most promising approach to the solution of the suit temperature and moisture control problem is to supply breathing and cooling air, conditioned by a facility mounted, compressor type cooler to a "semi-closed" life support undersuit separate from the

bio-barrier outer suit. This undersuit is to have a permeable membrane, sealed on its outer surface, and open at the extremities, through which conditioned air can be drawn to provide body cooling and moisture control.

The way in which this life support concept was developed has been portrayed in 2-2.2 A. Early tests which compared the gross efficacy of the air and liquid cooling system for the purpose of validating analytical trade-offs indicated the following differences between the first version of the G.E. developed air-cooled suit and the B. Welson water cooled suit.

(6) Test Results

G.E. developed air-cooled suit versus B. Welson water cooled suit.

TABLE VI - UNDERSUIT TEST COMPARISONS
G.E. DEVELOPED AIR-COOLED SUIT

ADVANTAGES	DISADVANTAGES
(a) Good humidity and pollutant gas control of the suit atmosphere.	(a) The undersuit construction is relatively bulky and somewhat restricting to the subject's arm and leg motions.
(b) Light weight of the undersuit.	(b) Feed and exhaust hoses are large in cross section and therefore are rather cumbersome to manipulate.
(c) Good temperature control of the cooling air.	
(d) There is no restriction on the availability of breathing air.	
(e) Every point within the suit or tunnel can be maintained at a pressure below the chamber pressure.	
(f) System leakage within the suit creates no problem.	

B. WELSON WATER COOLED SUIT

ADVANTAGES	DISADVANTAGES
(a) The coolant has high heat capacity, and so heat transfer is quit efficient.	(a) A rather elaborate temperature control system is required because of the sensitivity of the system.
(b) The suit does not restrict body movement.	(b) Separate breathing air supply and exhaust lines are required in addition to water supply and return lines.
	(c) The water cooled undersuit provides no positive humidity or noxious gas control.
	(d) Leakage and seepage might be a problem over a long period of operation.

Conclusions: It was concluded that both systems required further study and testing before a final air versus water cooling and moisture control determination could be made. Such tests will be conducted in the next quarter.

2-2.3 Communications

A. Status of Concept

The primary effort expended on the BISS communications system has been directed towards the definition and fabrication of a mock-up system. Little effort has as yet been applied to such broad problems as definition of communication link requirements and control philosophy for the final system. However, these problems will be dealt with during the remainder of the program. Therefore, the current communications concept is geared primarily for Phase II mock-up use. It is probable that many features of the present system will be equally suitable in the final BISS configuration, but such a conclusion must await further study. The following summary characterizes the presently conceived BISS communications system:

- All normal speech sounds are faithfully reproduced with a signal-to-noise ratio of at least 12 db and frequency response within 3 db from 300 to 3500 Hz.
- Neither the BISS operator nor test conductor has to perform any switching function. Continuous, two-way, talk-at-will type communications are available.
- Volume levels on links to and from the suited operator are independently adjustable.
- Component reliability is high and the possible incorporation of a failure warning system is now being evaluated.
- Communications transducers (speaker and microphone) are mounted on the undersuit, directly below the operator's chin.
- It will be possible to interconnect several additional monitoring stations with the test conductor.
- Several suits may be connected to the link in the present concept, but at present they may not communicate directly with each other.
- A chamber speaker (heavy duty exponential horn) is used as the primary system back up if the link to the operator should fail.
- A heavy duty alarm with a guaranteed sound level of 98 db at ten feet is used as the secondary backup if there should be a total failure of communications to the subject.

- An alerting horn actuated by a panic button inside the chamber will serve as a back-up if communications from the suit to the test conductor should fail. The principal means of determining the status of the operator will be direct vision of the operator by the external personnel. Therefore, if the operator is spoken to by the test conductor and appears to be responding, but is not heard by the test conductor, it will be obvious to the test conductor that there has been a communications failure.

B. Development of Concept

Analytical comparisons were made in two areas to support the development of the communications concept portrayed in 2-2.3 A. A summary of the results of these analyses follows.

(1) BISS Operator's Communications Transducer Selection

The transducer configurations considered for use in the BISS were:

(a) Headset and throat microphone

(b) Headset and boom microphone

(c) Single suit-mounted speaker/microphone

(d) Separate suit-mounted speaker and microphone

Approaches (c) and (d) appeared to have the most promise in view of the potential impediment to suit entry and exit posed by head mounted transducers. Phase I mock-up experience ruled out (c) because switching is required and a single volume setting must be used for transmit and receive at both ends of the link. It became apparent that no single setting could be found which was satisfactory for both the BISS operator and the test conductor. Therefore, the present concept embodies alternative (d) for a separate, suit-mounted microphone and speaker. This concept will be further extended by a planned investigation of noise-cancelling microphones that may be located several inches from the operator's mouth and very small, high reliability speakers.

(2) BISS Operator's Method of Actuating the Communications System

The following alternatives were considered:

(a) Push-to-talk

(b) Voice-actuated turn-on

(c) Talk when not receiving (outside switching required)

(d) Talk-at-will

Alternatives (c) and (d) emerged from the analysis as having the greatest merit. The relative economy and simplicity of (c) dictated that it be tried first. The requirement for any switching on the part of either the test conductor or the suited operaotr was found undesirable. Further, open links in both directions permit instant alerting in either direction if a hazardous condition should arise. Therefore, alternative (d) (talk-at-will) is now incorporated in the concept.

2-2.4 Human Factors and Man-Machine Analysis

A. Status of Concept

The following problem areas have been identified for investigation during the course of the BISS program. The current status of the concept in each area is summarized below.

(1) Entry and Egress

The operator will enter the chamber by means of a reefing tube having parallel sides and a semicircular top and bottom. He will sit upright at the inner end of the tube and don the outer suit which will be held in position by a donning rack. Donning will be accomplished by the operator first inserting his legs into the suit, followed by his arms, and finally positioning the helmet-yoke assembly as he rises into an erect position. Egress will involve attachment of the suit to the donning rack and exit through the reefing tube or hatchway.

(2) Work Shift Duration

Currently it is not possible to predict if the system design goal of four hour work shifts can be met. The focus of present activities is on the promotion of operator comfort and the reduction of operator fatigue by improvemnt of the design of the life support and suit subsystem. Tests will be conducted during the Phase II mock-up program to empirically determine operator endurance in the BISS and work shift strategies will then be developed on the basis of this data.

(3) Operator Comfort

The interplay of suit fit and overpressure effects are viewed as the most significant elements in the operator's physical comfort. Psychologically, the sensation of air flow, particularly in the helmet, contributes substantially to the operator's feeling of well being.

(4) Vision

Operator vision in the BISS is dependent upon both the optical qualities of the helmet material and the size and shape of the helmet. A modified "bubble" type helmet which is supported by a shoulder yoke provides freedom of head movement (the bubble remains stationary as the head moves), and excellent optical qualities if fabricated from Lexan or some equivalent material. The yoke is secured under the wearers arms to permit the operator to bend without having the helmet shift position. Such a helmet (See Figure1) can readily meet the visual field criteria for BISS.

(5) Mobility and Dexterity

Operator mobility is promoted by the use of a soft suit with only a small amount of reinforcement. All such reinforcements (e.g. support rings) are located so that they do not restrict joint motion. The main impediment that the operator must contend with is a force of about 30 lbs/in. of water pressure which exists in those intermittent periods at which the tunnel is not fully collapsed. This condition occurs briefly during retraction for reefing or extension of the tunnel when the operator walks out into the chamber. However, once this brief period is concluded, operator mobility is vastly improved. The overpressure seems to have no effect on finger dexterity so that this problem is reduced to one of glove sizing and materials selection. A thin cotton underglove will be worn by each individual to absorb perspiration and to offer some degree of glove sizing adjustment.

(6) Communications

Human factors inputs have been improved to the communications system design effort specifying that a two-way, open link with independent volume controls is required between the test controller and the suited operator. Definition of operational links between suited operators and director and monitor personnel located outside the chamber will be defined in conjunction with communications subsystem design personnel during the forthcoming quarter.

(7) Suit Fit

Early conceptualization of outer suit fit was to size the suit for the 30th through 80th percentile (height and weight) male, American, civilian population. Mock-up experience suggests that a more homogeneously sized operator population may be required since looseness of fit tends to inhibit operator mobility in the overpressure environment.

(8) Special Tools

No study has yet been made of special tool requirements for the BISS operator. These requirements (if any) will be identified during the remainder of the program.

(9) Work Procedures

The fact that the reliability of spacecraft assembly and checkout operations to be performed in the Assembly/Sterilizer is of the highest importance, coupled with the limitations imposed on personnel by operating in the BISS, suggest the importance of detailed work planning in mission success. While it is not within the scope of this contract to develop such procedures, BISS considerations bearing on such planning will be identified in the final report.

(10) Operator Selection

Formal study has not yet been directed at the problem of operator selection. Certain factors are apparent such as that the operator cannot be claustrophobic and should be in good physical health. Equally obvious is the fact that the man must conform to suit sizing and job skill requirements. More detailed selection criteria will be developed during the coming quarter.

(11) Operator Training

The training requirements for the BISS operators will be developed in the second quarter. To date no effort has been expended in this area.

B. Development of Concept

(1) Entry and Egress

Phase I mock-up tests clearly indicated the inadequacy of the first concept for helmet support which required mating of a helmet neck ring mounted on a shoulder harness worn into the chamber by the operator. It was found that the shoulder harness impeded the subject in sitting up in the tunnel and also that the neck ring mating operation was very difficult to perform. The unitary helmet-yoke assembly, discussed in Section 2-2.1 emerged as a solution to these findings.

The shape of the reefing tube or hatchway has been modified to facilitate operator passage and outer suit donning. The original concept was for a circular tube and the current one is for the more anthropomorphically shaped hatchway described in Section 2-2.4 A. Also, it was found that entry and egress is facilitated by the reduction of any friction surfaces on the undersuit. While early thinking had the inner suit made of neoprene rubber to facilitate mobility and fit, this material offers too much friction for easy passage into and out of the hatchwat and BISS suit. The current concept for the undersuit, discussed in 2-2.1, Suit Tunnel and Hatch, offers a solution to this problem.

(2) Work Shift Duration

As stated in 2-2.4 A, mock-up experience to date suggests that some modification of the original four-hour, uninterrupted work period may be required. At the present time, a four-hour work shift is still the design goal. The Phase II mock-up study will provide data which will allow a careful evaluation of the adequacy of this concept.

(3) Operator Comfort

From the outset of the program, it has been recognized that a number of factors including suit fit, life support system adequacy and the operator's view of system safety, all influence operator comfort. The interaction of human factors personnel with life support and safety personnel has helped to strengthen the system concept in these areas, but the primary focus of the human factors effort has been on suit fit, as influenced by the overpressure environment.

While it was conceived early in the program that a loose outer suit would permit a wider selection of operator body sizes to be used, mock-up tests with overpressure have indicated that the overpressure forces the loose outer garment close to the operator's body and inhibits outer suit movement as body members are extended in work simulation. As a consequence, the outer suit is now conceived of as a more closely fit garment, especially on the front surface.

It has also been recognized that operator comfort and hygiene will be promoted by the use of personally-sized thin cotton undergloves, a soft pliable cotton cap and heavy socks or slippers. All of these items will absorb moisture and personal oils. The undergloves and socks (or slippers) can also help to make sizing adjustments for operators who must fit into the single size of outer suit boots and gloves.

(4) Vision

Design of a bubble type helmet with good optical properties does not appear to be a problem. The size of this helmet (see Section 2-2.1) is rather large to permit sufficient head movement to satisfy BISS visual field criteria. Lexan currently appears to be the leading candidate material for providing essentially distortion free vision and also being able to withstand sterilization environments.

(5) Mobility and Dexterity

The evolution of the concept for operator mobility and dexterity are intertwined with those for suit and tunnel. The only change in suit concept which has been directed primarily at operator mobility was the outer suit sizing change. The addition of the hatchway piston, discussed in 2-2.1 B, to the system concept also was directed at promoting operator mobility. This device aids the operator by preventing collapse of the tunnel into the hatchway.

During the coming quarter, a literature search on gloved hand and finger dexterity is to be conducted to assist in definition of an optimum glove size and configuration for use in the final BISS.

(6) Communications

The BISS communications investigation has concentrated on the mock-up study. During the coming quarter, effort will be expended on definition of communication link and control requirements for the ultimate BISS.

(7) Suit Fit

The early concept of outer suit fit was that of an outer suit which would permit comfortable fit for the 30th to 80th percentile operator population. This concept has been modified as a result of in-chamber pressurization tests. These tests have indicated, as mentioned earlier, that looseness in fit tends to inhibit operator movement as a result of chamber overpressure pressing the outer suit to the operator's body. It is therefore conceived that the outer suit will have to be relatively more form fitted in the front, with some slack in the armpit area down to the waist. The absence of slack in the ventral waist-to-boot area is necessary to facilitate mobility.

The inner suit must be relatively form fitted on a personal, operator-by-operator basis. This approach will provide for general comfort through good fit, optimization of cooling air flow, and will preclude the development of any chafing at body pivot points.

2-2.5 Safety

A. Status of Concept

The emphasis of the safety effort has been on the identification of potential hazards in both the mock-up and final Assembly/Sterilizer system configurations. Tentative problem solutions have been developed which are responsive to several of the identified hazards. Further effort will be expended on all these tasks during the coming quarter.

The potential hazards which have been identified are:

(i) Insufficient oxygen available to BISS occupant's breathing zone to:

- Maintain the alertness necessary to safely perform work tasks.
- Sustain consciousness.
- Support life.

(ii) Presence of noxious or toxic contaminents, at the BISS occupant's breathing zone in sufficient quantity to:

- Reduce occupant's capability to perform normal or emergency operations in a safe manner.
- Cause acute illness requiring emergency egress.
- Cause unconsciousness.

(iii) Presence of irritant/toxic contamination on suit interior, detrimental to the occupant's well being.

(iv) Accidental injury to BISS occupant as a result of:

- Slipping and falling.
- Being struck by a falling object.
- Striking head against a protruding structure.
- Contact with an electrically charged object.
- Ignition and burning of BISS material.

(v) Accidental ignition of electro-explosive device during handling due to static electricity accumulation on BISS material.

(vi) Isolation of BISS occupant from external assistance in event of illness or injury.

Presently conceived solutions to hazards (i), (v), and (vi) are presented on the following pages.

(1) Emergency Breathing Air Supply

The primary safety consideration in this area is assuring the maintenance of the breathing air supply to the occupant's breathing zone. To this end, a requirement for a highly reliable life support system is specified in the safety criteria. Precautionary measures to minimize the potential of kinking or severing the breathing air supply lines leading from the life support unit to the BISS occupant are to be incorporated in the design. Such factors as tubing flexibility, service life under operating environments and connector integrity will be evaluated during the remainder of the program.

The 100% nitrogen atmosphere envisioned for the Assembly/Sterilizer appears to provide one of the most potentially hazardous aspects of the BISS operating environment. This implies that the BISS operator is primarily dependent on maintaining adequate oxygen for breathing from an externally supplied source. It also indicates that anyone attempting to provide emergency assistance to an operator within the chamber would also require a source of breathing oxygen.

In view of the nature of these hazards, and the realization that no complex system of this nature can be considered 100% reliable, an emergency back-up breathing air supply is being proposed. The purpose of this emergency supply is to ensure that the operator has sufficient time to exit from the chamber in the event of failure of the normal breathing air supply without invoking rescue procedures which would violate the sterility of the chamber. In establishing the time that should be allocated for a BISS operator to exit the chamber, it was considered that in a worst-case condition the occupant would be involved in a complex assembly operation while standing on an elevated work platform when his air supply was lost. It was felt that, if possible, the occupant should be able to terminate a critical assembly operation in safe manner, (5 minutes), walk down the platform stairs and return to the BISS hatch (5 minutes) and then exit from the BISS into the external normal atmosphere (5 minutes), for a total of 15 minutes of emergency supply required.

Several alternate approaches to providing this emergency supply have been considered to date and study will continue in this area. From a safety viewpoint, the prefered solution to this

problem appears to be an oxygen-enriched back-up air supply (50/50 by volume) located within the suit envelope. However, this solution is highly tentative, and will be evaluated in a detailed trade-off study covering all factors involved.

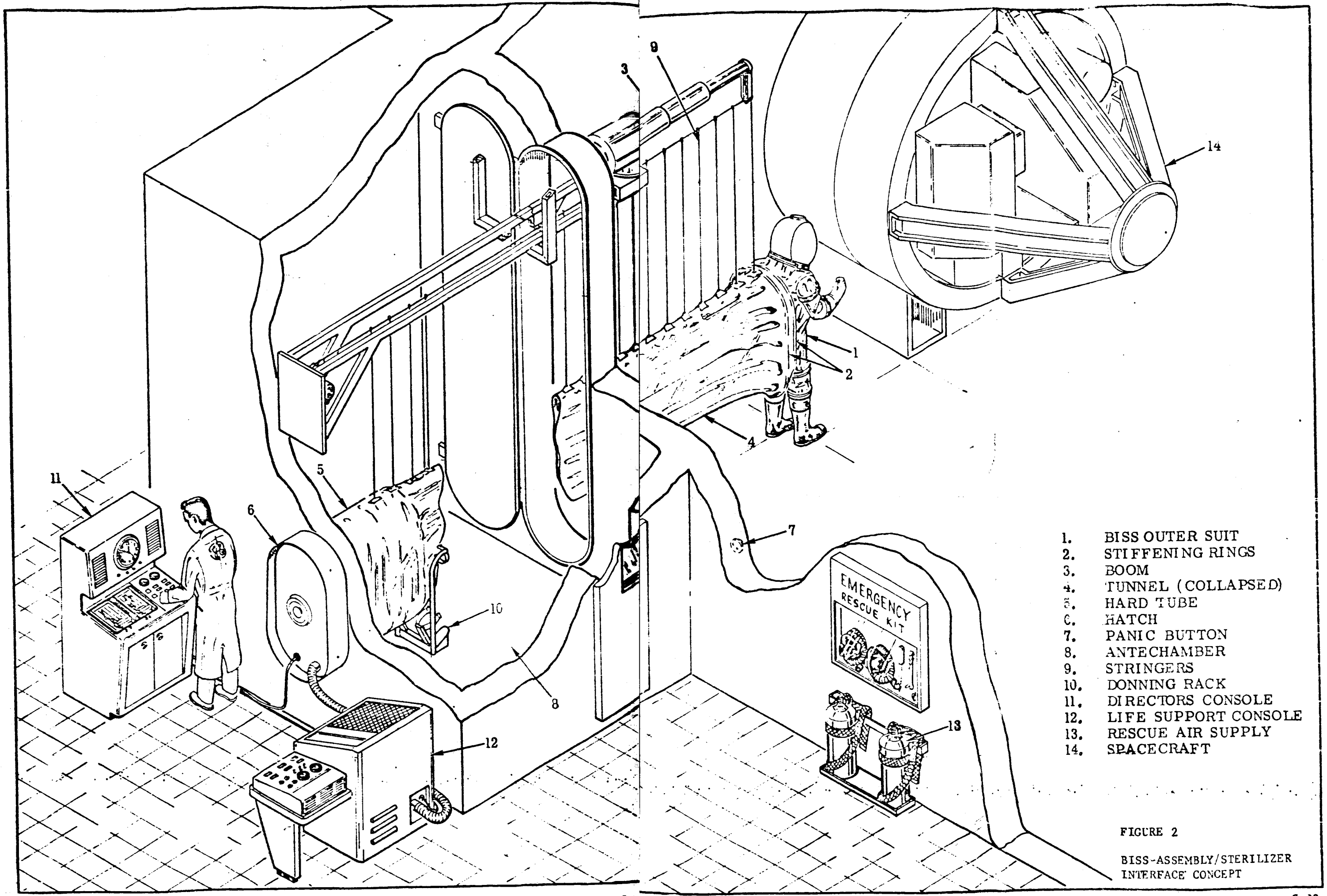
(2) Operator Injury Protection

It is anticipated that the BISS design will provide good visibility and mobility; however, some degree of limitation in both these areas is inherent in the system. This fact tends to increase the hazard potential of the occupant, particularly while working on elevated platforms. Also, an injury sustained while in the BISS could hamper the ability of egress, and make first aid difficult to administer. For these reasons, the safety criteria include such features as a helmet with hard-hat characteristics, face shield, safety toed shoes, and non-skid boot soles. A more detailed analysis of all potential hazards listed in (iv) above, will be made during the forthcoming quarter.

(3) Emergency Egress

A worst-case accident situation analysis indicates that a BISS operator could become unconscious and be in need of emergency first aid due to a heart attack, breathing air loss, or severe accidental injury. Although the probability of such a situation occuring appears extremely small, it is felt that provisions to affect the rescue of an operator in such a situation should be incorporated in the overall concept. As a minimum, it was determined that the chamber layout and suit mobility should be such that a BISS operator requiring assistance could be reached by another operator at any location in the chamber.

In view of the bio-integrity requirements of the BISS, providing for rapid occupant egress is a difficult problem. The currently conceived approach to the emergency rescue requirement involves the use of an antechamber which can be quickly sealed from the Assembly/Sterilizer Chamber atmosphere by means of a remote controlled hatchway door. This antechamber, illustrated in Figure 2, will provide a suitable environment to which a BISS occupant can be carried without violating the main chamber's bio-integrity. After a rescuer carries a disabled operator to the antechamber, and then leaves the antechamber himself, the hatchway is closed and the antechamber can be vented to the outside atmosphere, to allow entry of unprotected personnel. If necessary, the BISS can be cut open to gain access to the occupant. The time required to effect such venting and rescue will be



1. BISS OUTER SUIT
2. STIFFENING RINGS
3. BOOM
4. TUNNEL (COLLAPSED)
5. HARD TUBE
6. HATCH
7. PANIC BUTTON
8. ANTECHAMBER
9. STRINGERS
10. DONNING RACK
11. DIRECTORS CONSOLE
12. LIFE SUPPORT CONSOLE
13. RESCUE AIR SUPPLY
14. SPACECRAFT

FIGURE 2

BISS-ASSEMBLY/STERILIZER INTERFACE CONCEPT

→2-32

determined during the next quarter. The antechamber will be sterilized prior to re-opening the hatchway to the main chamber.

Further study of emergency egress provisions will be conducted to identify and evaluate still other conceptual problem solutions. When the various possible solutions have been defined and evaluated, a detailed safety analysis will be conducted to determine the degree to which the safety criteria have been satisfied.

B. Development of Concept

A trade-off was conducted to support the development of the emergency breathing air supply concept. Auxiliary air compressor systems, compressed oxygen or air tanks located external to the BISS envelope, and compressed oxygen or air bottles located within the BISS envelope were considered as back-up breathing air supply alternatives.

(1) Trade-Off

Compressor, versus External Bottled Air, versus Internal Bottled Air Emergency Breathing Supply.

TABLE VII - BACK-UP GAS SUPPLY TRADE-OFF

BACK-UP AIR COMPRESSOR SYSTEM FOR EACH LIFE SUPPORT SYSTEM

ADVANTAGES	DISADVANTAGES
(a) Moderate Cost	(a) Will be affected by power failure, which may be cause of initial life support subsystem failure.
(b) Low maintenance requirement.	(b) Will not provide air if supply tube to BISS is broken or blocked.
(c) Curently available.	(c) Requires a person or a mechanisn to initiate operation in timely manner.
(d) Air supply not time limited.	

BACK-UP COMPRESSED OXYGEN OR AIR BOTTLES FOR EACH LIFE SUPPORT SYSTEM (LOCATED EXTERNAL TO BISS).

ADVANTAGES	DISADVANTAGES
(a) Not affected by power failure.	Same as (b) and (c) above
(b) Same as (a), (b), (c),	

ADVANTAGES	DISADVANTAGES
and (d) above. ((d) assumes the availability of a large number of back-up tanks or bottles).	

BACK-UP OXYGEN OR AIR SUPPLY BOTTLE LOCATED WITHIN BISS, CAPABLE OF BEING INITIATED EITHER BY OCCUPANT OR BY SOMEONE EXTERNAL TO THE BISS.

ADVANTAGES	DISADVANTAGES
(a) Not affected by supply tube integrity.	(a) Added weight for BISS operator to carry.
(b) Independent of power failure or other external problems.	(b) May require a limited amount of development for optimum utilization for this purpose.
	(c) Supply time limited.

Conclusions: The third alternative was preferred since it is the only approach yet proposed that will assure the availability of breathing air to the operator when the need is most likely. It is felt that the major disadvantages of weight and bulk can be minimized through engineering planning and development.

Consideration was also given to the composition of the back-up air supply. Although 100% oxygen would have a therapeutic effect upon certain cases of operator illness or fatigue, it would also provide a potential fire hazard within the BISS and might compromise the communication equipment due to non-sparking requirements, etc. Therefore, it was concluded that an oxygen - enriched air composition, about 50/50 by volume, would offer the best compromise between oxygen and fire/explosion safety requirements.

2.2.6 BISS Maintenance

A. Status of Concept

The effort applied to the development of the BISS maintenance concept, to date, has been limited. The main effort has been devoted to initial definition of a maintenance location in which suit-tunnel repair and/or replacement can be executed without jeopardizing the sterility of the Assembly/Sterilizer.

The current concept invokes the use of an independently sterilizable antechamber as the place in which the BISS maintenance and/or replacement will be performed. Use of the antechamber for safety rescue is discussed in Section 2.2.5. Its maintenance use is supported by the fact that any other location for suit-tunnel maintenance is likely to result in violation of Assembly/Sterilizer bio-integrity.

Other issues which will be investigated during the remainder of the program are:

- Recommended schedules for suit and tunnel repair and replacement.
- Checkout and preventive maintenance requirements and techniques.
- Definition of suit-tunnel repair techniques.
- Analysis of maintenance requirements for life support and communications subsystems.

B. Development of Concept

The initial analysis which supports development of an antechamber for BISS maintenance activities considered three possible locations for these activities. These areas were: (a) within the Assembly/Sterilizer, (b) exterior to the Assembly/Sterilizer, and (c) within an antechamber to the Assembly/Sterilizer. A brief discussion weighing the merits of each follows.

(1) Maintenance Within the Assembly/Sterilizer.

Since preliminary maintenance generally occurs within the area of operation, performing maintenance in the Assembly/Sterilizer itself was considered as the first possibility. It was concluded that this approach was unacceptable because the rigid checkout testing contemplated to assure the integrity of the suit-tunnel subsystem could jeopardize the sterility of the main chamber. Specifically, any tracer

gas used to pressurize the subsystem for post repair checkout purposes might leak into the Assembly/Sterilizer and also transport microbes, present in the suit interior, into the sterile chamber.

(2) Maintenance External to the Assembly/Sterilizer

Recognizing that the ideal maintenance location did not lie within the Assembly/Sterilizer, the next step was to consider the area immediately outside the Assembly/Sterilizer in which supporting subsystems are situated. Consideration of how suit-tunnel replacement might be effected indicated that chamber sterility would almost certainly be violated by this process when the suit-tunnel subsystem was replaced.

(3) Maintenance in an Antechamber

Just as bio-integrity will be maintained between the chambers of the Assembly/Sterilizer, bio-integrity can be maintained between an antechamber and the Assembly/Sterilizer main chamber. Necessary maintenance can be performed within the antechamber or exterior to it. Although antechamber sterility is lost in the process, it may be restored by means of a heat sterilization operation. Thus the antechamber can be sealed off from the main chamber, required maintenance can be performed, the antechamber and its contents can be sterilized, and then the antechamber can be re-opened to the main chamber.

2.2.7 Biointegrity and Leak Detection

Mass spectrometric and radioisotope tracer methods have been investigated to make a preliminary determination of the feasibility of detecting leaks in the suit system with tracer gases. The details of the investigation are discussed in Appendix B. The radioisotope tracer method promises significantly greater sensitivity than helium leak detection by mass spectrometer, but both methods require limited dilution of the tracer gas. This places a significant design constraint on the suit and tunnel if leak detection is to be performed on a real-time or a near-real-time basis. Two approaches are suggested; compartmentation of the suit and tunnel, or double-wall construction of the suit and tunnel. Compartmented sampling would be desirable in any event, and double wall construction would permit either sampling of the small volume between the walls or filling the small volume with sterile tracer gas and sampling on either side of the wall. These concepts will be further advanced to determine their feasibility.

A leak detection technique employing micron-size aerosolized particles of fluorescein is being developed by McDonnel Aircraft Corp. for NASA/Marshall. Details of the technique will be investigated and their applicability to BISS determined.

No method has yet been devised to distinguish between many small holes and a few large ones. The pattern of appearance of holes in materials may be elucidated through the materials tests of task IV and provide a basis on which to set limits for leak rates for the suit system.

2.2.8 Specifications

A principal output of the program will be the set of specifications called for by the statement of work. Thus far, no effort has been directly applied to this task since these specifications can only be written at the conclusion of both the concept development and mock-up study efforts. However, unless serious shortcomings of the Phase II mock-up system come to light in task V, there should be a great deal of similarity between the Phase II mock-up specifications (now in process) and the final system specifications.

2.3 TASK III - INTEGRATED TEST PLAN

The draft of the Integrated Test Plan was completed during the quarter and sent to NASA Langley technical representatives for review. The plan covers both the materials testing of Task IV and the mock-up test program Task V. The mock-up test program consists of two phases: Phase I, Developmental Tests; and Phase II, Evaluation Tests. Materials Tests span both phases of the mock-up test program.

The Phase I mock-up tests concentrate on the selection of competing components and subsystems for the first generation BISS mock-up. Components, subsystems and an entire mock-up system will be tested during Phase I. At the end of the Phase I development effort, experience gained during this period and the results of materials studies completed during Phase I will be integrated and applied to the Phase II procurement specifications. After receipt of hardware, the Phase II mock-up will be assembled to evaluate the performance of the system.

The preliminary test and demonstration plan for the BISS engineering model (to be developed under a subsequent contract) will be developed after completion of the materials tests and the Phase II mock-up tests so that the information and experience of these test programs may be evaluated and fed into that plan.

The Integrated Test Plan contains the following -

- Phase I Development Tests - General Description
- Phase II Evaluation Tests - General Description
- Materials Tests - General Description
- Appendix A - Detail Mock-up Tests and Subject's Assessment Scale
- Appendix B - Detail Materials Tests
- Appendix C - Test Plan Schedule

The integrated test plan is summarized in the following sections, the reader is referred to the Test Plan itself for details.

2.3.1 Mock-Up Test Plan

A. Test Facility

A Tenney Altitude Chamber, located at the General Electric Chestnut Street plant in Philadelphia has been modified to serve as a pressure chamber for up to 4 inches of H_2O pressure

(gage). Chamber temperature will be at normal ambient and the BISS occupant's environment will be controlled by the suit life support system. The personnel access door in the chamber has been displaced and a hatch assembly substituted for it (see figure 3). This assembly will provide a proper interface for the suit tunnel. Included in this hatch assembly are a metal reefing tube through which the subject enters the chamber and a knock-out panel for emergency entrance and exit. Other special support items which have been fabricated for the tests include a monitor's work stand (see figure 3) and a donning rack to assist the BISS occupant in entering and leaving the suit.

B. Test Team

The test team will be made up of the BISS occupant (subject), a test conductor, a medical monitor, and a chamber technician. The test conductor will be located immediately adjacent to a chamber window and will direct all actions of the subject via the communications system. He will collect data from the subject as different tasks are done and will direct all test operations.

The medical monitor will monitor an RKG (Radio Cardiogram) and respiration and collect gas samples (gas into and out of the helmet) as well as monitoring all test conductor - subject communications. At any time the medical monitor feels that there is cause to terminate the test or question the subject, he will do so. Additionally, the medical monitor will watch the gages on the subject's breathing supply (for tests in which this is used), and will be responsible for making any adjustments to this system. Both the test conductor and the medical monitor will note any portion of the subject's performance which is suspect and will question him regarding it at an appropriate time.

The chamber technician is primarily responsible for maintaining the desired pressure level in the chamber. Since this task will not load him heavily, he will be able to provide assistance to the test conductor as needed.

Two subjects have been selected for the Phase I tests. It is planned that all Phase I tests will be run on one subject, with the other as back-up. Phase II tests will utilize four subjects and one back-up.

C. Test Procedures

Test data will be collected by a combination of objective measurements (e.g. pressure, temperature, timing exit and entry) and subjective ratings. The subjective ratings are referred to as Subject's Assessment Scale (SAS).

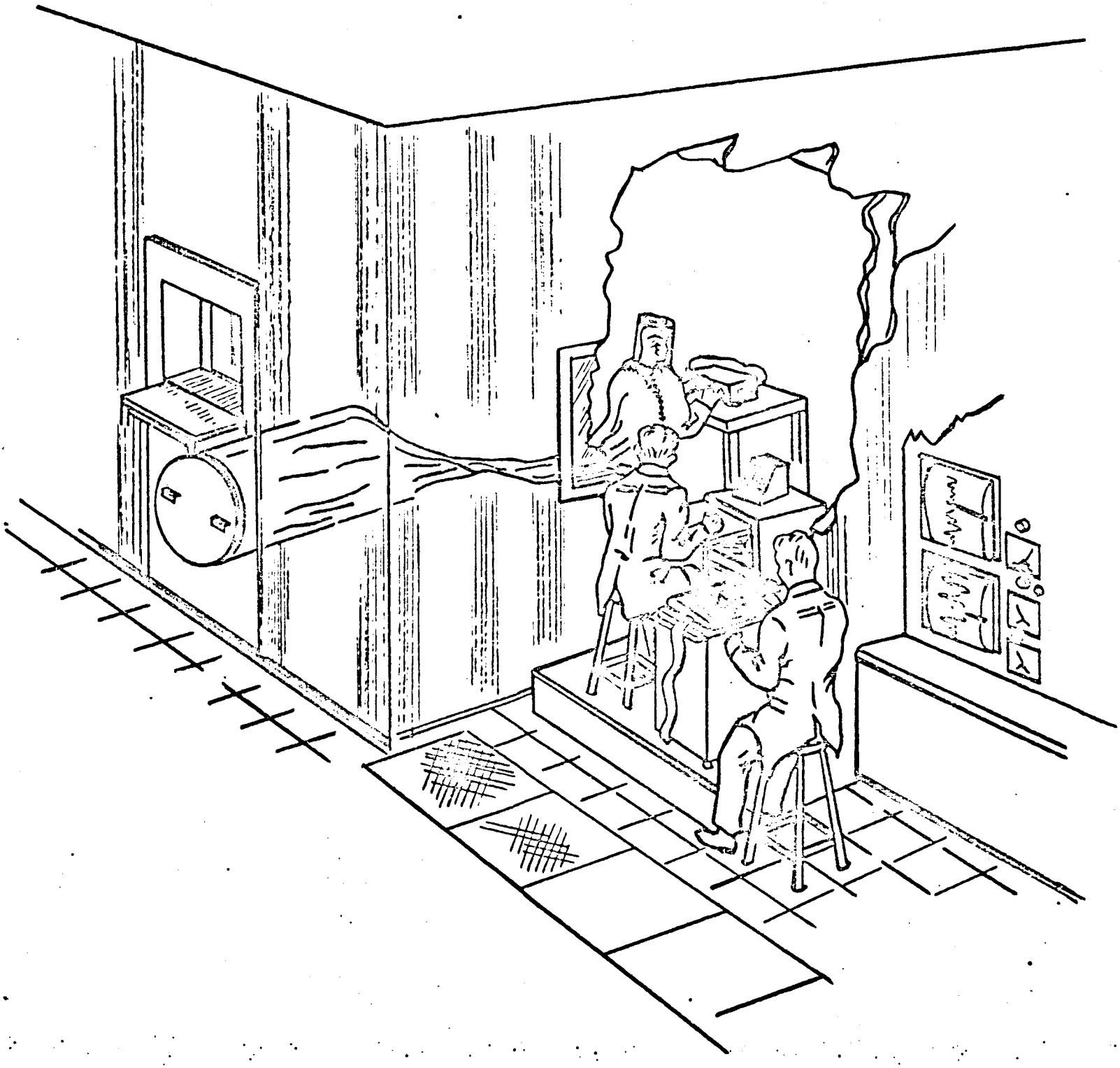


Figure 3 Hatch Assembly/Monitor's Workstand

Fundamentally, the SAS identifies parameters which are salient to the functioning of the BISS and asks the subject to rate the performance in terms of these parameters on a seven point scale. A rating of seven implies excellent performance while one means unsatisfactory performance, with intermediate numbers representing shadings of good or bad performance. While data collected in this way cannot represent absolute values, it is an effective technique for gaging relative performance. Any biases which the subject might have should remain constant over the tests and therefore the impact of the same test conducted under different conditions or the same test before and after some hardware modification should be apparent. Use of multiple subjects in the Phase II tests will permit ascribing more universality to the data collected than to the Phase I data.

Five Subject's Assessment Scales will be used as follows:

I Comfort

(a) Overall Comfort
(b) Temperature
(c) Humidity
(d) Cooling Distribution

II Mobility

(walking, climbing, bending, squatting)

III Dexterity

(a) Use of hand tools
(b) Handling of small objects
(c) Mating and demating of electric and hydraulic connectors

IV Entry/Exit

(a) Ease of Entry/putting on suit
(b) Ease of taking off suit/Exit

V Communications

(a) Loud speaker placement in helmet
(b) Signal intelligibility
(c) Communications effectiveness

Medical and life support monitoring data will be collected for fully suited tests (e.g. cooling system inlet and outlet temperatures, relative humidity, gas flow rate, RKG, respiration, and gas composition). When a subject is performing test tasks, records of the medical and life support parameters will be made. Changes in these values will be noted. Test record sheets will be designed so that the medical/life support measurements recorded by the test conductor and the medical monitor can be correlated with the relevant subject actions, ratings and comments.

D. Phase I Tests

Table VIII A herein summarizes the development tests which will be performed during Phase I on the mock-up test program. A brief description of each test follows.

(1) Life Support

Tests will be performed on two competing systems for providing cooling air to the air-cooled undersuit: (1) A Vortex tube cooling system, and (2) an air-conditioner operating in conjunction with a blower. The flow rate and temperature ranges for the two competing air cooling systems will be established, and the temperature rise and the flow rates at the extremities of the air distribution harness will be measured. It has been determined from literature search that the following tentative flow rates are appropriate for BISS: 2.4 cfm to the helmet, 3.6 cfm in each arm hand and 3.2 cfm in each leg.

At the conclusion of the two tests, a comparative evaluation of the realtive merits of the vortex tube and air conditioner systems will be made. The one which best meets the flow and temperature control criteria will be selected for future use with the air-cooled undersuit. The other candidate air-cooling system will be discarded from further consideration in this study.

(2) Subsystem Tests

The subsystem tests are designed to establish the basic functioning of the subsystem elements in the BISS and to provide an indication of adjustments or modifications which may be required to optimize subsystem performance.

(a) Chamber Pressurization

This test will establish the capability of the chamber's seals to withstand pressurization up to 4 inches of water and to be held at this pressure.

(b) Undersuit

The subsystem tests of the competing air cooled and water cooled undergarments are to be conducted under ambient pressure conditions. In both tests, the ability of the undersuit to cool the subject while resting and after exercise will be determined. Temperature and flow rate data will be collected at various points in the subsystem. Section I of the Subject's Assessment Scale (SAS) will be administered to the subject verbally while resting and after exercising to establish the perceived comfort of the subject. Onset of both the high and low temperature discomfort regions will be identified and the subject will be questioned about deficiencies he observes in the performance of the undersuits.

TABLE VIIIA

SUMMARY OF PHASE I MOCK-UP TESTS

TEST	PRESSURE	TEMP	SUIT Manned	SAS Section Used	DATA COLLECTED	COMMENTS
COMPONENT TESTS						
Vortex Tube Life Support	Ambient	Ambient	N/A	---	Flow Rate & Temp. Data	
Air Conditioner Life Support	Ambient	Ambient	N/A	---	Flow Rate & Temp. Data	
SUBSYSTEM TESTS						
Chamber Pressurization	4"H_2O	Ambient	No	---	Chamber Pressure achieved & input pressure req'd.	
Water Cooled Undersuit	Ambient	Ambient	Yes	Section I	Fluid flow rate Inlet fluid temperature Subject Temperatures Determination of onset of high and low temperature discomfort zones	Subject tested under resting conditions and after exercise
Air Cooled Undersuit	Ambient	Ambient	Yes	Section I	Supply Temp. at flow tube Subject Temperatures Time to Reach Temp. Equilibrium Determination of onset of high and low temp. discomfort zones	Subject tested under resting conditions and after exercise
Leak Test	4"H_2O	Ambient	No	---	Leakage Rate, Chamber Pressure	Determine capability of maintaining pressure in chamber with suit attached.
Helmet Air Supply	Ambient	Ambient	Yes	Section I Parts a-c	Input pressure, respiration, gas composition, heart rate	Determine optimum flow rates for comfort
Visual Field	Ambient	Ambient	Yes	---	Vertical and horizontal angular Displacements at which subject can see a test marker	
Outer Suit Fit	Ambient	Ambient	Yes	---	Subject's Appraisal of Fit	

(c) Outer Suit/Tunnel

(i) Gross Leak Test

The suit-tunnel leak test will be run with the chamber pressurized at 4 inches of H_2O, the suit-tunnel attached to the reefing tube and a pressure gage or manometer attached to the tube. The objective of this test will be to determine if the suit-tunnel has gross leaks and to minimize any such leakage so that chamber pressure can be maintained for further suited tests in the chamber. This test will be repeated for both the 10 foot tunnel used in the early subsystem tests and the subsequent 20 foot tunnel.

(ii) Helmet Air Supply

The helmet air supply test is designed to assure the basic functioning of the helmet air distribution system under ambient conditions and to identify an optimum air flow rate for initial use in the chamber tests.

(iii) Visual Field

The visual field possible in the BISS helmet will be measured by means of a standard visual field test. The criteria to be met are 140° vertical (80° below the line of sight, 60° above) and 220° in the horizontal plane. If these criteria cannot be met, the helmet will be reworked to meet the criteria.

(iv) Fit

The outer suit will be tried on by the subject over both undersuits in an ambient pressure environment. Fit will be adjusted as necessary by removing or adding material to permit optimum freedom of movement for the subject. Breathing air and cooling will be supplied to the subject during this test.

(d) Safety - Rescue

The safety-rescue tests are intended to assure that if a mishap should occur during the mock-up tests it is possible to effect a timely rescue of the subject. No back-up air or rescue air supply will be needed since the chamber will contain breathable air and the subject's isolation from the chamber can be readily broken by use of a zipper in the outer suit. This zipper is located across the subject's chest.

Rescue operations will be conducted in the chamber under both ambient and differential pressure conditions. The total time to effect rescue under wither condition must be less than four minutes. The chamber's built in "panic button" (klaxon) will be exercised by the subject during this test to assure its proper operation.

(e) Communications

The communications subsystems test will be conducted under an ambient pressure environment to assure proper functioning and adjustment of the system and to optimize transducer placement within the helmet.

(f) Tunnel Reefing Subsystem

The initial BISS subsystem tests will be conducted with a 10 foot tunnel clamped to the outer surface of chamber side of the reefing tube. Though this approach permits only a crude form of tunnel reefing to be accomplished, it will be adequate for the subsystem level tests. Concurrent with the conduct of the subsystem tests, an independent tunnel reefing subsystem will be in the final stages of development. As the last element in the subsystem tests, this reefing system (using a 20 foot tunnel) will be tested and mated with the outer suit.

(3) System Tests

(a) Suit System

The suit system tests are designed to exercise the manned suit system and to assess subject's comfort and physiological response to the environment (under both resting and exercising conditions), mobility, chamber/suit entry-exit and communications. These tests will first be carried out at ambient pressure and then under a differential pressure condition. Both undersuits will be tested under the differential pressure condition.

The subject will be directed to perform a sequence of tasks and the Subject's Assessment Scale will be used to obtain evaluative data. The data collected, plus any observations of the subject relative to difficulties not covered by the SAS, will be reviewed after each test and remedial action will be taken, as appropriate. The tests will be performed with the water cooled and air cooled undersuits. For each undersuit, the tests will be conducted once with no differential pressure and twice with differential pressure.

Mean ratings for the SAS items will be computed for comparison with comparable data to be obtained from the Phase II tests.

Records will be made of observed deficiencies and corrective actions for guidance in the preparation of the specifications at the end of the Phase I development effort. The undersuit receiving the poorer overall rating (summation of mean scores on the SAS items) will be eliminated from further consideration in this study.

E. Phase II Tests

Table VIIIB summarizes the test which will be performed during Phase II of the mock-up test program. These tests will be applied to the second generation BISS mock-up. It is expected that only a minimum amount of initial adjustment will be required by the second generation system. Therefore the tests discussed in the following text reflect only the formal testing effort and do not enumerate any shakedown tests. All Phase II tests will be performed on four subjects, completely outfitted in the BISS.

(1) Anthropometric Measurements

In order to ascertain more precisely than is possible from the SAS the degree of encumbrance imposed by the BISS on the operator, a series of comparative anthropometric measures of the motions of the head and arms of non-suited versus suited subjects will be made.

(2) Entry-Exit Tests

Each of the four subjects will be run through a series of five timed entry-exit tests. Preceding the five timed trials there will be a familiarization trial for each subject. Entry will be defined as the time elapsing from entry of a fully undersuited subject into the exterior opening of the reefing tube until the fully suited man emerges into the chamber. The time required for exit will be the converse of the foregoing process. Three minutes is the design objective for either of these operations with ten minutes as an upper limit.

(3) Mobility

The mobility of the subject will be appraised by use of Section II of the SAS as was done in the Phase I Tests. The subject will be asked to rate each facet of the suit's mobility via the BISS communication system as he completes the relevant action. Walking, climbing, bending at the waist, and squatting will be tested. All subjects will go through exactly the same routine to insure comparability of rating data.

(4) Dexterity

It would be possible to use commercially available tests to assess operator dexterity in the suited and unsuited condition, but it is believed that more relevant data can be obtained by the use of an analogue assembly task. The assembly test object is shown in Figure 4 . Its assembly and disassembly will require the use of common hand tools and will also involve the mating and demating of representative electrical and hydraulic connectors.

SUMMARY OF PHASE II MOCK-UP TESTS

TABLE VIII 5

TEST	PRESSURE	TEMP.	SUBJECT CLOTHED IN	SAS Section Used	DATA COLLECTED	NO. OF SUBJECTS	COMMENTS
Anthropometric Measurements	Ambient	Ambient	1) Common work clothes 2) BISS Outfit	---	Anthropmetric measurements in undersuit and in full BISS Outfit	4	
Entry - Exit Tests	Up to 4" H_2O	Ambient	BISS Outfit	Section IV	Times for subject to enter chamber fully suited and for exit operation	4	Subject will be given five trials
Mobility Tests	Up to 4" H_2O	Ambient	BISS Outfit	Section II	SAS ratings obtained for walking, climbing, bending & squatting	4	Subjects will be given three trials Instructions given over intercom.
Dexterity Test	Up to 4" H_2O	Ambient	1) Normal Work clothes 2) BISS Outfit	Section III	Times to assemble and disassemble test object in suited and unsuited conditions	4	Assembly and disassembly instructions given over intercom.
Communications Test	Up to 4" H_2O	Ambient	BISS Outfit	---	Errors in receiving phonetic nonsense syllables.	4	Both subject and test conductor will transmit lists over intercom; Test conductor will transmit over chamber speaker.
Subject Endurance	Up to 4" H_2O	Ambient	BISS Outfit	Entire SAS less Section IV, Items Va & Vb	Reactions of subject, length of time subject remains in chamber	4	SAS portions administered once an hour.

TABLE VIII B (CON'T)

TEST	PRESSURE	TEMP	SUIT Manned	SAS Section Used	DATA COLLECTED	COMMENTS
Safety Rescue	(1) Ambient (2) Up to 4"H_2O	(1)Ambient (2)Ambient	Yes	---	Time to (1) gain access to subject (2) free subject (3) remove subject from chamber	Goal-4 minutes detection of difficulty to removal of subject
Communications	Ambient	Ambient	Yes	Section Va Section Vb	Subject's reactions to placement of speaker. Intelligibility of signals received in and from the helmet. Intelligibility of chamber Loud Speaker.	Life support and Monitoring Systems operating at Normal Settings
Tunnel Reefing	a. Ambient b. Up to 4"H_2O c. Up to 4"H_2O	a. Ambient b. Ambient c. Ambient	a.No b.No c.Yes	---	Reefing Time	Design Goal - 2 minutes Max. 4 min.
SYSTEMS TESTS Suit System	a. Ambient b. Ambient c. Up to 4" H_2O d. Up to 4" H_2O e. Up to 4" H_2O f. Up to 4" H_2O	a. Ambient b. Ambient c. Ambient d. Ambient e. Ambient f. Ambient	a. Yes - Air cooled Undersuit b. Yes - Water - cooled Undersuit c. Yes - d. air cooled Undersuit e. Yes - f. water - cooled Undersuit	Section I II IV Item Vc	SAS data and test team/ subject observations	Data to be used to determine undersuit selection.

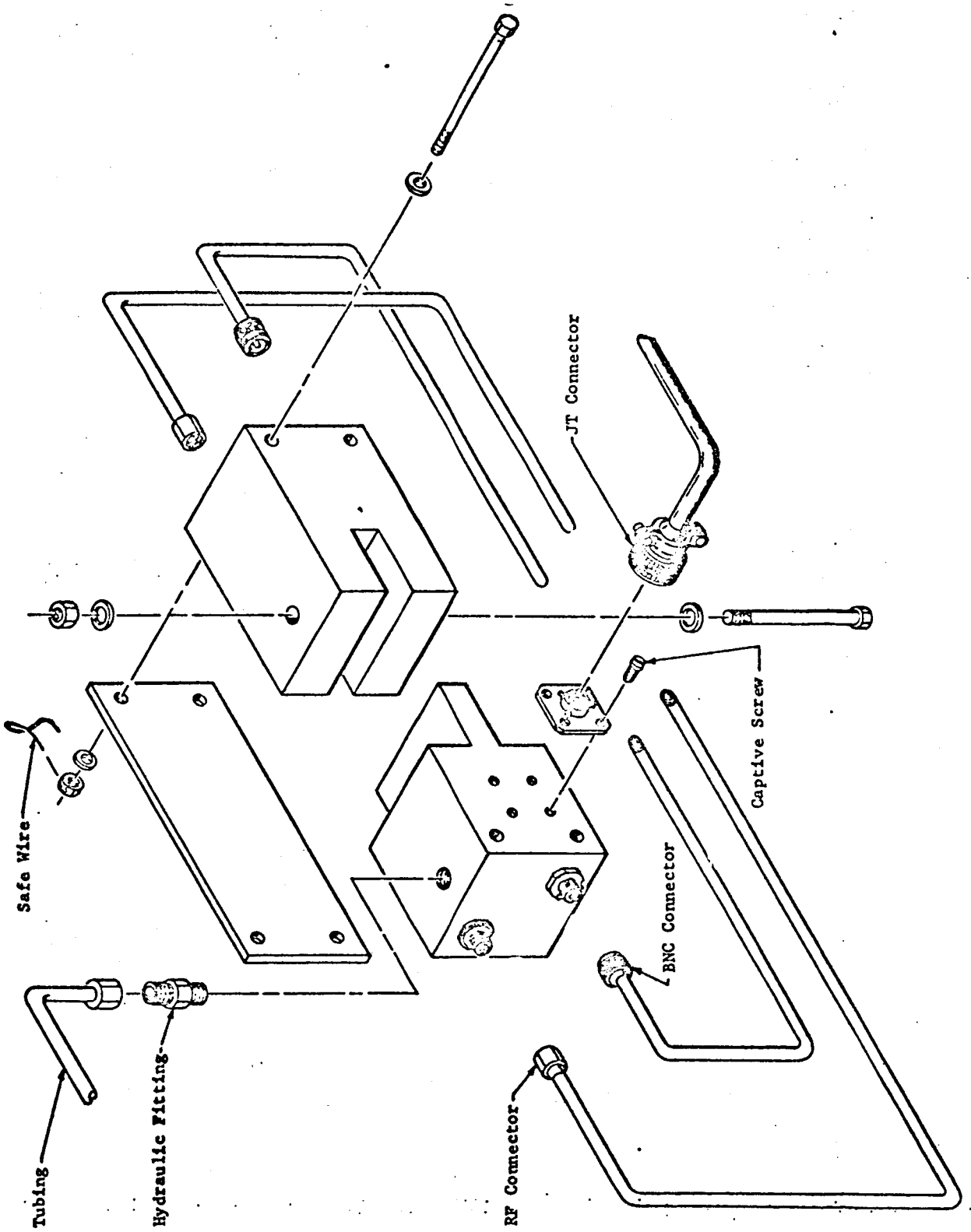


FIGURE 4 ASSEMBLY TEST OBJECT

(5) Communications

Phoenetic nonsense syllables will be used to assess the adequacy of the intercom communications link between the subject and the test conductor. Each subject will be read a list of fifty such syllables. Each syllable will have a sequential number associated with it. The subject will mark the number next to the syllable received on a printed list containing the fifty test syllables intermixed with fifty other syllables.

An abbreviated version of another such list (twenty-five syllables to be transmitted, fifty on the list) will be used to assess the chamber speaker's adequacy. The first test (fifty syllables transmitted) will be repeated with the subject transmitting and the test conductor marking the answers.

(6) Subject Endurance

The criterion for acceptable endurance of the operator in the BISS environment is four hours. After all other tests have been completed, each of the subjects will be put through a four hour endurance trial. During this period the assembly test object, used for dexterity testing, will be assembled and disassembled several times and movement about the chamber will be permitted as desired by the subject. A stool will be provided on which the subject may rest. Once an hour the entire SAS (less Section IV Entry-Exit and Item V.a and V.b for subsystems communications test) will be administered over the intercom.

If the subject desires to leave the chamber prior to the expiration of the four hour period, this will be permitted. A test will be promptly terminated on the advice of the medical monitor.

If, however, at the end of the four hour period, both the subject and the medical monitor concur, the test will be extended until either the subject or the medical monitor directs its termination. The purpose of such an extension of the endurance test would be to establish a gross feel for the upper limits of subject endurance in the BISS environment.

(7) Hygiene

Tests of the application of helmet internal disinfection will be performed in accordance with test 9 of Table 3 to evaluate the adequacy of the disinfecting technique.

F. Final Mock-Up Data Analysis

At the conclusion of the Phase II evaluation tests, the data derived from all the tests will be evaluated. Conclusions resulting from the evaluation will be incorporated in the final BISS specifications and the prime BISS Test and Demonstration Plan. When possible, comparison

will be made between the Phase I and Phase II data to assess the degree of improvement if the Phase II system over the Phase I system. A summary of the results of the final data analysis will be included in the final BISS program report.

2.3.2 Materials Tests

The overall objective of the BISS materials testing program is to define optimum materials for use in the BISS outer suit. These materials must withstand the thermal, chemical, and mechanical stresses planned for the assembly sterilizer facility and provide a barrier to microbiological and fungicidal penetration. The materials used for the Phase I mock-up suit have been recommended as a result of early analytical materials study; likewise, the materials of the phase two suit will reflect the results of subsequent materials studies and tests. It is required that the materials used for the mock-up suits simulate the weight and stiffness of the final material, but there is no need that this material possess the thermal, chemical and mechanical tolerances or microbiological impenetrability of the final suit.

A series of tests designed to assess the physical properties of candidate materials for the outer suit will be run throughout the term of the program. Materials which have been identified as a result of analytical studies will be subjected to competitive evaluations. The tests included in this evaluation are summarized in table IX.

Table X is a matrix showing the materials testing to be performed on the program. For each treatment listed on the left of the table, appropriate tests will be conducted as indicated on the right. The maximum numbers of tests indicated reflect the performance of treatments of varying intensity (number of temperature cycles, number of disinfectants, number of abrasion and flexure cycles) in triplicate. Attempts will be made to reduce the number of tests by making use of preliminary data to make early evaluation of materials. If the data is indicative of unfavorable results, further testing of the candidate materials will be discontinued.

II-3.3 Test Plan Schedule

The schedules for the test programs are presented in figures 5, 6, and 7 covering the Phase I mock-up tests, Phase II mock-up tests, and materials tests respectively.

SUMMARY OF MATERIAL TESTS

TABLE IX

	TEST	OBJECTIVE	APPLICABLE SPEC/STD	COMMENTS
1	Fungus Growth Test	Determine if material supports growth of fungi	MIL-STD-810A MIL-F-8261A	Test Fungi Aspergillus niger Aspergillus flavus Myrothecium verrucaria Penicillium citrinum
2	Mycelial Penetrability Test	Determine if materials are penetrable by mycelia of filamentous fungi	MIL-STD-803A, Procedure II modified MIL-F-8261A	Test Fungi as for Test 1
3	Permeability/Flexure	Prepare Specimens for further testing		
4	Abrasion	Prepare Specimens for further testing		Materials abraded for 100, 500, and 1000 cycles
5	Transfer of Microorganisms and Gases Across Suit Materials Part I	Determine materials to serve as microbiological barriers-Determine if gas leaks are indicators of membrane holes		Suit materials exposed to radioactively labeled bacteria or radioactive gas. Microorganisms selected from Micrococcus rubeus Micrococcus candedus gases used will be C^{14} Carbon Dioxide or Krypton 85
6	Transfer of Microorganisms Liquids & Gases Across Suit Materials Part 2	Determine permeability of suit materials to water vapor and gas		Water vapor detection by Karl-Fisher Titration Method ETO by gas chromatography
7	Retention & Release of Disinfectants by materials	Determine degree of absorption/ retention of ETO/Freon Isopropanol Peracetic Acid		ETO determinations by gas chromatography Isopropanol by wet chemistry Peracetic Acid - Titration with ceric sulfate

TABLE 1X (Con't.)

	TEST	OBJECTIVE	APPLICABLE SPEC/STD	COMMENTS
8	Compatibility with Detergents and Disinfectants	Prepare Specimens for further testing after exposure to disinfectants and detergents		Disinfectants/Detergents ETO Peracetic Acid Isopropanol 5% Triton X-100
9	Evaluation of Disinfectants	Determine if helmet can be disinfected		Test Organisms Staphylococcus aureus Mycobacterium phlei
10	Tensile Test for Rigid, Solid & Laminated Plastics	Determine tensile properties	ASTM D-638	
11	Tensile Test for Flexible Plastic Sheeting	Determine tensile properties	ASTM D-882-64T	
12	Puncture Resistance	Determine ability of plastic suit material to withstand puncture	ASTM E-154-60T Modified	Test modified to simulate 50 lb. thrust from a screw driver shaped plunger.
13	Optical Transmittance	Determine decrement of Transmittance of face-plate materials after exposure to applicable environments		Optical transmittance for BISS is in the 0.4 - 0.7 micron wave length range
14	Weight Change	Determine weight change of plastics after exposure to applicable environments		Materials exposed to ETO peracetic acid, isopropanol, temperature cycling, and abrasion
15	Impact Test for Plastic Materials	Determine capability of helmet and face-plate materials to withstand 125 ft. lbs. impact		Failure Criteria determined visually.
16	Temperature Aging	Expose test specimens to temperature aging for further testing		Specimens exposed to 5, 10 and 20 cycles of 160°C 3 hrs.

TABLE IX (Cont-d)

TEST	OBJECTIVE	APPLICABLE SPEC/STD	COMMENTS
17 Tear Resistance	Determine tear resistance of plastic sheeting	Fed Std 406 Method 1121	
18 Compressive Properties	Determine compressive properties of helmet and faceplate materials	Fed Std 406 Method 1021	
19 Lap Shear	Determine tensile shear strength of adhesive bonded composites		
20 Butt Tensile	Determine tensile strength of adhesive bonded composites		

TABLE 7 MATERIALS TEST MATRIX AND TEST QUANTITIES (1)

MATERIALS \ TEST NO. (7)	VIRGIN MATERIAL	TREATMENT 16	7	4	3	TEST 1	2	5	6	8	10	11	12	13	14	15	17	18	19 (2)	20
SUIT		x						72				72	72		72		72			
		x		x				216							216					
		x			x			216												
			x(3)									48	48		48		48			
	x					24	24	24	48(3)			24	24				24			
				x				72							72					
					x			72												
			x(3)	x				144							144					
			x(3)		x			144												
		x(5)	x(5)									6	6		6		6			
		x(5)	x(5)	x(5)				6												
HELMET	x					12			36(4)	12	12					12		12		
		x									36				36	36		36		
			x(4)								36				36	36		36		
		x(6)	x(6)	x(6)							6				6	6		6		
				x											12					
FACEPLATE	x					12			36(4)	12	12			12		12		12		
				x										36	36					
		x									36			36	36	36		36		
		x		x										108	108					
			x(4)								36			36	36	36		36		
			x(4)	x										108	108					
		x(6)	x(6)	x(6)							6			6	6	6		6		
BONDING	x					12	12	12											12	
					x			36											36	
		x																	36	
		x			x			108											108	
			x(3)																24	
			x(3)		x			72											72	
		x(5)	x(5)																6	
		x(5)	x(5)		x(5)			6												

NOTES:

NUMBERS IN ( ) REFER TO NOTES. SEE FOLLOWING PAGE.

NOTES FOR TABLE X

(1) Numbers in the body of the table indicate the maximum number of tests performed.

(2) Lap Shear or butt tensile tests will be performed as applicable.

(3) Peracetic acid and ETO only.

(4) Ethylene oxide, peracetic acid, and detergent/isopropanol.

(5) Two selected suit and two selected bonding materials in triplicate will be subjected serially to ETO, temperature aging, and abrasion or flexing as indicated and then tested for physical properties, microbial and gas permeability.

(6) Two selected faceplate and two selected helmet materials in triplicate will be subjected serially to ethylene oxide treatment, temperature aging, and abrasion as indicated and then tested for physical properties.

(7) Numbers in the heading of the table refer to the number of the test or treatment as listed on pages 2-54 through 2-56 of this report.

BY

DATE

TEST PLAN SCHEDULE

MOCK-UP TESTS

1966 | PHASE I | 1967

ITEM	SEPT					OCT					NOV										DEC					JAN					FEB				MAR	
	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	1	2	3	4	5	6	7	8	9	10	11							
I. DEVELOPMENTAL TESTS																																				
A. COMPONENT TESTS																																				
1. LIFE SUPPORT																																				
GAS FLOW/TEMPERATURE TESTS						▲	▼																													
VORTEX TUBE COOLING SYSTEM																																				
GAS FLOW/TEMPERATURE TESTS											▲	▼																								
AIR CONDITIONER COOLING SYSTEM																																				
B. SUBSYSTEM TESTS																																				
1. LIFE SUPPORT																																				
a. CHAMBER PRESSURIZATION											▲	▼			▲	▼																				
2. UNDERSUIT																																				
WATER COOLED UNDERSUIT																	▲	▼																		
AIR COOLED UNDERSUIT																			▲	▼																
3. OUTER SUIT/TUNNEL																																				
a. LEAK TEST																			▲	▼																
b. HELMET AIR SUPPLY																			▲	▼																
c. VISUAL FIELD																			▲	▼																
d. FIT																			▲	▼																
5. SAFETY-- RESCUE																			▲	▼																
6. COMMUNICATIONS																			▲	▼																
7. TUNNEL REEFING																			▲	▼																
C. SYSTEM TESTS																																				
1. SUIT SYSTEM																																				

→2-5

BY

DATE

FIGURE 6

TEST PLAN SCHEDULE

MOCK-UP TESTS

ITEM	1966 SEP 36	37	38	39	40	OCT 41	42	43	44	45	NOV 46	47	48	49	50	DEC 52	53	1967 JAN 1	2	3	4	5	FEB 6	7	8	9	MAR 10	11	12	13
II. EVALUATION TESTS																														
A. ANTHROPOMETRIC MEASUREMENTS																														
B. ENTRY - EXIT TESTS																														
C. MOBILITY																														
D. DEXTERITY																														
E. COMMUNICATIONS																														
F. SUBJECT ENDURANCE																														
G. APPLICATION OF HELMET INTERNAL DISINFECTION																														
H. FINAL DATA ANALYSIS																														

PHASE II

2-60

→2-60

2-60

BY

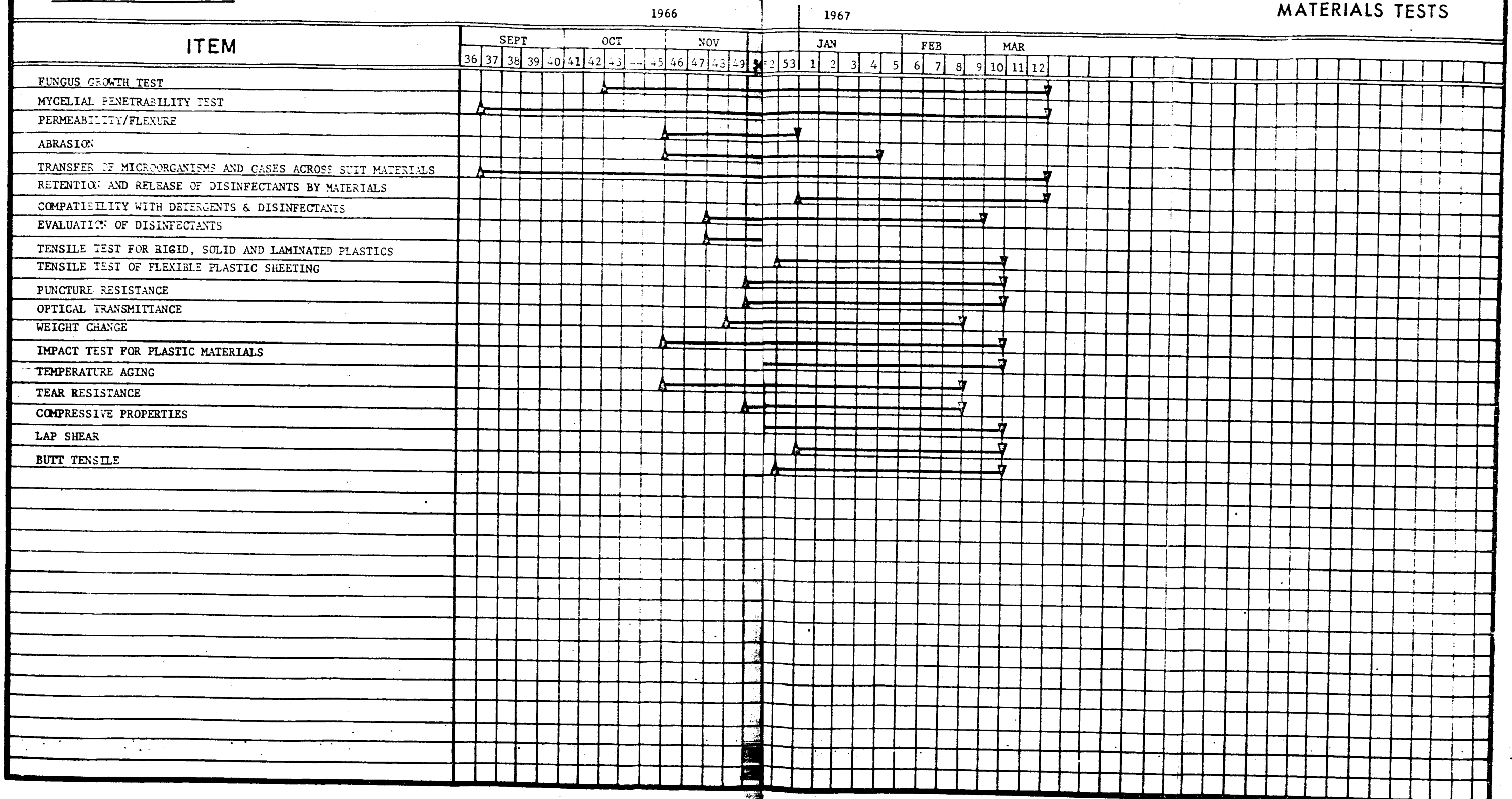
DATE

FIGURE

TEST PLAN SCHEDULE

PAGE 3 OF 3

MATERIALS TESTS



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2-61

2-61

2.4 TASK IV MATERIALS ANALYSIS

2.4.1 Materials Selection

In support of the system criteria and concept investigations and trade-offs, materials areas of concern were identified and general material requirements were determined. The various material areas are:

- Helmet/Face-Plate
- Suit and Tunnel
- Gloves and Boots
- Bonding and Gasketing Materials

It should be noted that in order to assure as leak-free a system as possible, the usage of bonding and gasketing materials must be held to an absolute minimum.

General material requirements were established for candidate materials to satisfy the BISS Concept. These are:

- Stability to dry-heat sterilization
- Minimum ETO/Freon permeability/degradation
- Impervious to micro-organisms
- Abrasion resistance
- Low coefficient of friction (Suit and Tunnel)
- Highly resistant to flexure and puncture
- Resistance to liquid decontaminants
- Impact resistant (Helmet/Face-Plate)
- Maximum retention of Optical Clarity (Face-Plate)
- Non-flammable
- Minimize static electricity build-up

Based upon the general material requirements in relation to specific suit system, areas trade-offs were made of possible candidate materials. The candidate materials are:

- Suit and Tunnel

  1. Butyl Rubber/Fabric
  2. Vinylidene Fluoride/Fabric
  3. Polyimide/Fabric
  4. "Armalon" (Teflon/Teflon fabric)
  5. Overcoats to reduce permeability, such as "Saran" or gold coatings.

- Helmet

  1. Epoxy-glass rigid structure
  2. Overlays to reduce permeability, such as "Saran", "Teflon", Butyl Rubber

- Face-Plate

  1. Optical glasses
  2. Polycarbonates
  3. Protective overlays of "Saran"

- Boots and Gloves

  1. Silicone rubber
  2. Butyl rubber

Based on the characteristics of the identified candidate materials for the BISS suit system, availability/fabricability trade-offs were made to identify suitable materials for the mock-ups to be used in task V. The materials were chosen to permit the best possible simulation of the identified candidate BISS materials consistent with reasonable cost and level time for the mock-up fabrication.

TABLE XI

MOCK-UP MATERIALS

	Phase I	Phase II
Inner Suit	Neoprene rubber with Scott foam bounded to the inner surface with B35B adhesive (Roberts Consolidated Industries).	To be defined
Outer Suit	PVC coated cotton fabric bonded with Pliobond (Goodyear)	Plastic coated fabric
Boots	PVC coated cotton fabric	Elastomeric or elastomeric coated fabric (relatively stiff)
Gloves	Synthetic rubber	Elastomeric or elastomeric coated fabric
Helmet	Methacrylate cylinder	Refined shape and material
Tunnel	PVC coated cotton fabric	Plastic coated fabric

2.4.2 Investigation and Testing of Physical Properties

Physical properties of candidate BISS materials are under investigation through literature search, supplier consultation, and laboratory testing. This investigation is concentrated on materials for a prime BISS suit and tunnel, with sufficient investigation of mock-up materials to assure reasonable simulation of prime BISS materials and to assure suitability for the mock-up.

The materials under investigation to date are:

Armalon 408-128, 8 mil

Armalon 414-141, 14 mil

Poly (vinyl chloride) coated fabric (Mock-up suit material), 20-21 mil

Poly (vinyl fluoride) film, 1 mil

FEP Teflon film, 1 mil

Kapton Polyimide film

Gold coated polyimide

Poly (vinyl chloride) film, 17-17.5 mil

CR-39 allyl diglycol carbonate

Properties of a number of candidate materials have been compiled, including physical properties, gas and water vapor permeability, flammability, and electrical properties. These data are included in Appendix C.

At the request of NASA/LRC, GE also investigated "OMNI" fabric.

The vendor of this material (David Clark Company) was contacted for information. The vendor stated that the marketing program for this material was discontinued early in 1966 due to lack of customer interest. Small quantities may be available for evaluation, and efforts have been initiated by GE to obtain a quantity for limited screening.

The physical testing of materials to-date has been restricted to Abrasion testing of Lexan and Polyimide using a Taber Abraser, 1000 gm force, with a CS-10 wheel. Based on 9 samples of each material, the following data was obtained.

Lexan

Weight Loss, milligrams	7.7
Wear Index (Weight loss method)	7.4

Polyimide

Weight Loss, milligrams	23.2
Wear Index (Weight loss method)	22.7

Equipment for Physical testing of materials is shown in Appendix D.

2.4.3 Chemical and Biological Testing

Several Chemical and Biological properties of candidate materials for the BISS are under investigation by laboratory testing. Evaluation of these properties, together with evaluation of the physical properties will provide the data required for selection of suitable materials for the BISS. Initial tests have been performed on fungus growth and fungus mycelial penetration and preparatory work has been done for testing permeability to microorganisms and gases.

A. Fungus Test - MIL-F-8216A

Experimental studies were initiated to evaluate the resistance of candidate materials to fungal attack. Table XII lists the materials tested to date and the test results. The test of Armalon A-414 is being repeated to verify the positive on fungus growth.

TABLE XII

FUNGUS GROWTH TEST

MATERIAL	CONTROL	MATERIAL TEST
Armalon A-414	Positive	Positive
Armalon A-408	Positive	Negative
Gold Coated Polyamide	Positive	Negative
CR - 39	Positive	Negative
Kapton	Positive	Negative

B. Mycelial Penetration of Materials by Fungus

A procedure was evolved from the MIL specification for fungus testing (MIL-F-8216) to permit evaluation of the penetration of materials by fungal mycelium. The test consists ot two nutrient media separated by the candidate material so that fungal spores placed adjacent to one side of the material grow normally as a sub-surface culture. Mycelia penetrating the material are detected in the culture medium on the other side. Even though special glass cylinders have been fabricated to hold the detecting medium, an unforeseen difficulty was encountered in this test in that some spores present in the medium migrate with the slightest agitation to the top of the testing cylinders and give false positive type results. The existing test set-up is shown in figure 8 .

The present method of testing is undergoing revision to overcome this problem and the materials will be retested.

The candidate materials under test are the same as those listed in A above.

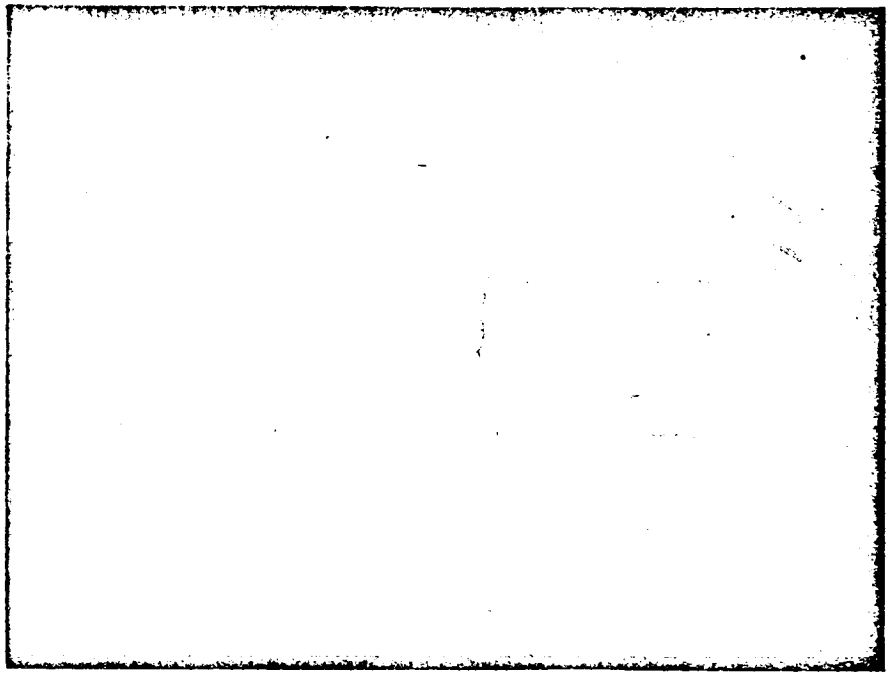


Figure 8 . Test set-up for Mycelial Penetration of Materials by Fungus

C. Disinfection of Helmet and Face-Plate Materials

Studies were initiated to evaluate the following disinfection procedure:

- Swab the helmet with a cloth dampened with a 5% aqueous solution of Triton X-100
- Wipe with a dry cloth
- Apply 70% isopropanol with a damp cloth and allow to stand moist a minimum of five minutes.
- Dry with cloth
- Aerate with vacuum hose to remove traces of alcohol and odor from helmet.

The experimental protocol is described in the test plan.

D. Permeability of Materials to Microorganisms

(1) Preparation of Labeled Microorganisms

Radio-actively labeled microorganisms will be used in a study of the transfer of microorganisms across various candidate suit materials proposed for use in the BISS suit and tunnel

(a) Preparation of Calcium^{45} Labled Spores of Bacillus Subtilis var. niger

(i) Materials

((1)) B. subtilis var. niger (Bsn_1)

((2)) Gelysate Nutrient Medium

Gelysate	3.5 grams
$MnCl_2 \cdot 4H_2O$	.03 grams
$ZnSO_4 \cdot 7H_2O$	.005 grams
$FeSO_4 \cdot 7H_2O$	.001 grams
$CuSO_4$	.002 grams
glucose	1.25 grams

These constituent are combined and made to a volume of 1000 ml with distilled water, filtered through a 0.45 micron filter and autoclaved for 20 minutes at 15 PSIG.

((3)) Minimal Medium

$MgCl_2 \cdot 6H_2O$	0.12 grams/liter
K_2HPO_4 .	0.25 grams/liter
$MnCl_2 \cdot 4H_2O$	0.03 grams/liter
$ZnSO_4 \cdot 7H_2O$	0.005 grams/liter
$(NH_4)_2 SO_4$	1.00 grams/liter

Ca^{45} 10 microcurie /ml . (specific activity = 1 $\frac{\text{micro curie}}{\text{milli mole}}$.

or Ca^{45} 50 microcurie /ml

These constituents are made to a volume of 1000 ml with distilled water, filtered through a 0.45 micron filter, and autoclaved for 20 minutes at 15 PSI.

(ii) Methods

Bsn_1 cells were taken from laboratory stock cultures and cultured in 50 ml. of gelysate medium. The culture was maintained at 37°C and aerated by shaking. After 72 hours of incubation, the vegetative cells were harvested by centrifugation and washed once with filtered distilled water. The cells were then divided into four aliquots which were resuspended in minimal medium. Ten microcuries per ml was added to two of the aliquots and 50 ml microcuries per ml was added to the remaining two. The four cultures were incubated for 24 hours at 37°C after which, sporulation was approximately 95% complete. The cells were harvested and washed by filtration with a 0.45 micron filter. Ten 10 ml of wash water gave a background count of 10 counts per minute per ml. After re-suspension in 10 ml of filtered distilled water, population density was measured by means of a Petroff-Hauser counting chamber. Radioactivity was measured by a Baird-Atomic gas flow, low level, proportional counter (model nos. 727 and 146).

(iii) Results of Testing (for 10 microcurie/ml Ca^{45})

Cell count (re-suspension spores) = 9.25×10^9 cells/ml

Radioactivity = 4.7×10^8 counts/minute/ml

Relative specific activity of the spores = 5.1×10^{-2} cpm/spore

(v) Conclusions

No problems were encountered with spore production at 10 microcurie/ml. At 50 microcurie/ml spore population was not as complete or reliable. This is not thought to be due to the isotope but to an impurity associated with it. In view of the low specific activity obtained at 10 Mc/ml, means of removing the inhibiting agent or reducing its effect will be investigated. An optimal specific activity was not attained. This has the result of lowering the sensitivity of the Microorganism Transfer Test when these organisms are used. Past experience indicates that the specific activity of the spores can be increased to at least 5×10^{-1} dpm/spore. Subsequent tests will attempt to optimize the specific activity by limiting population density and by increasing the amount of Ca^{45} in the minimal medium. The labeled spore suspension obtained will be useful in testing the experimental chamber design and various counting geometries.

(b) Preparation of Calcium^{45} Labeled Spores of Bacillus cereus (Bc_1)

(i) Materials

((1)) B. cereus (Bc_1)

((2)) Gelysate Medium - same as in (a) above

((3)) Minimal Medium - same as in (a) above

(ii) Methods

Bc_1 cells were taken from laboratory stock cultures and cultured in 50 ml of gelysate medium. The culture was maintained at 37°C and aerated by shaking. After 24 hours of incubation, the vegetative cells were harvested by centrifugation and washed once with filtered distilled water. The cells were then divided into four aliquots and re-suspended in minimal medium. Ten microcuries per ml of Ca^{45} added to two aliquots and 50 microcuries/ml was added to the remaining two. The four cultures were incubated for forty-eight hours at 37°C, after which, sporulation was approximately 95% complete.

The cells were harvested and washed by filtration with a 0.45 filter. Ten ml volumes of filtered distilled water were used for washing. The last 40 ml of wash water gave a background of 15 counts per minute per mil. After re-suspension of 10 ml of filtered distilled water, population density was determined by means of a Petroff-Hauser cell counting chamber. Radioactivity was measured by means of of Baird-Atomic, gas flow, low level proportional counter (model nos. 727 and 146).

(iii) Results of Testing (for 10 microcurie/ml Ca^{45})

Cell count (re-suspended spores = 2.25×10^9 spores/ml

Radioactivity = 1.26×10^7 cpm/ml.

Relative Specific Activity = 5.6×10^{-3} cpm/spore

(iv) Conclusions

No problems were encountered with spore production at 10 microcurie/ml. At 50 microcurie spore production was not as complete or reliable. This is not thought to be due to the isotope but to an impurity associated with it. In view of the low activity obtained at 10 microcurie/ml, means of removing or reducing the activity of the inhibiting agent will be investigated.

(c) Preparation of Carbon^{14} Labeled Micrococci

(i) Materials

((1)) Micrococcus rubens, American Type of Culture Collection (ATCC) no. 186

((2)) Micrococcus candidus, ATCC no. 8425

((3)) D-Glucose -C^{14} uniformly labeled 200 millicuries/millimole

((4)) Gelysate Medium

((5)) Nutrient agar

((6)) Nutrient medium

(ii) Methods

M. candidus and M. rubens were received from the American Type Culture Collection in a lyophilized condition. The organisms were incubated for approximately 120 hours in nutrient medium at 25°C before growth occurred. Repeated subculturing was required until vigorous reliable growth was obtained. Growth studies were made in gelysate medium in order to compare the growth rate of the two organisms in a chemically defined medium. M. candidus was found to grow more rapidly than M. rubens reaching the maximum stationary phase in approximately 20 hours. M. candidus was chosen for use on this basis. The organisms were incubated in gelysate nutrient medium containing 50 microcurie/ml of c^{14} labeled glucose as the carbon source. The culture was aerated by shaking and incubated at 32°C for 16 hours. At the end of the incubation period the organisms were immediately harvested by filtration. They were then washed with seven 10 ml volumes of filtered distilled water. The wash water could not be reduced below 50 cpm/ml. This was apparently due to cell lysis or loss of soluble cellular constituents. Cell counts were made by means of nutrient agar pour plates and Petroff-Hauser cell counting chamber. Radioactivity was measured by a Baird-Atomic low level, gas flow, proportional counter (model no. 146).

(iii) Results of Testing (M. candidus)

cpm - total solution = 5.76×10^6 cpm.ml

cpm - Supernatant only = 2.4×10^6 cpm.ml

cpm - Unwashed cells = 3.36×10^6 cpm/ml

uptake by cells = 58.3%

cell count = 2.8×10^8

Relative specific activity = $\frac{3.36 \times 10^6}{2.8 \times 10^8} = 1.2 \times 10^{-2}$ cpm/bacterium

When counted on the model 727 counter the relative activity will improve by a factor of 10 due to improvements in efficiency and geometry. No difficulty is anticipated in obtaining a relative specific activity of approximately 1 dpm/bacterium. This will be accomplished by shortening the incubation time.

(d) Summary of Results

Organism	Isotope	Relative Specific Activity
Bacillus subtilis var. niger	Ca^{45}	5.1×10^{-2} cpm/cell
Bacillus cereus	Ca^{45}	5.6×10^{-3} cpm/cell
Micrococcus candidus	C^{14}	1.2×10^{-2} cpm/cell

Generally low specific activities were obtained with the result that the sensitivity of the method for transfer of microroganisms across various suit materials using these organisms would be about a factor of 10 less that planned. It is anticipated that the relative specific activities can be raised to the levels stated in the test plan (0.5 cpm/bacterium). This can probably be done in all cases by shortening the incubation time. No problems in growth or maintenance of reliable stocks of organisms have been encountered or anticipated. Testing of suit materials will be carried out using that organism having the highest relative specific activity with the C^{14} label.

(2) Construction and Testing of Test Chambers

(a) Summary

The object of this activity was the design and preparation of test chambers suitable for the testing of candidate suit material as biobarriers. It was required that these chambers fit into available isotope counting devices and that they be capable of holding a radioactive solution at 4" of water against the suit material under investigation.

Microorganisms labeled with calcium 45 and microorganisms labeled with carbon 14 were injected into test chambers containing PVC-coated cloth and PVC film. The chamber containing Ca^{45} gave a relatively high background (up to 164 cpm) while the chamber containing C^{14} labeled microorganisms gave a background of up to 36 cpm. The background was found to vary with either barometric pressure or temperature. This was minimized by having two legs of the chamber open to the atmosphere. For testing materials of the thickness being considered for the BISS suit and tunnel, carbon 14 is the isotope of choice. Calcium 45 can be ruled out because of its higher energy. It could, however, become useful if much thicker materials are to be tested or if it becomes necessary to employ a double label. The testing of prospective suit materials is feasible using the test chambers visualized in the Integrated Test Plan.

(b) Materials

(i) Standard 1" planchet holders

(ii) Candidate suit materials or material types

- Polyvinyl chloride coated fabric
- Armalon 408-128
- Polyvinyl chloride film
- FEP teflon
- "Kapton" - polyimide film
- Tedlar - Polyvinyl flouride film

(iii) Epoxi-Patch" epoxy resin

(iv) Lymphangiography outfits

(c) Methods

(i) Planchet Construction

Standard planchet holders were modified for the injection and retention under pressure of radioactive solutions. Various test materials (1" squares) were fixed to the milled-out portion of the planchet holders with epoxy resin. Planchets construction is shown in figures 9 , and 10. After curing at 70°C for 4 hours the chambers were leak tested by holding them at 20" of water for 3 minutes and at 10" of water for 15 minutes.

(ii) Backscatter Test

In order to determine whether backscatter would interfere with experimental determinations, discs of the test materials (7/8" diameter) were used as planchet backing for .01 ml of the B. cereus spore suspension. Their count rate was compared to that of a copper planchet with no backing material with the following results.

TABLE XIII

RESULTS OF BACK SCATTER TEST

Test Material	Background cpm	* CPM (hundreds of thousands)
Copper planchet	4	1.8
Copper planchet	5	1.8
Armalon	4	1.59

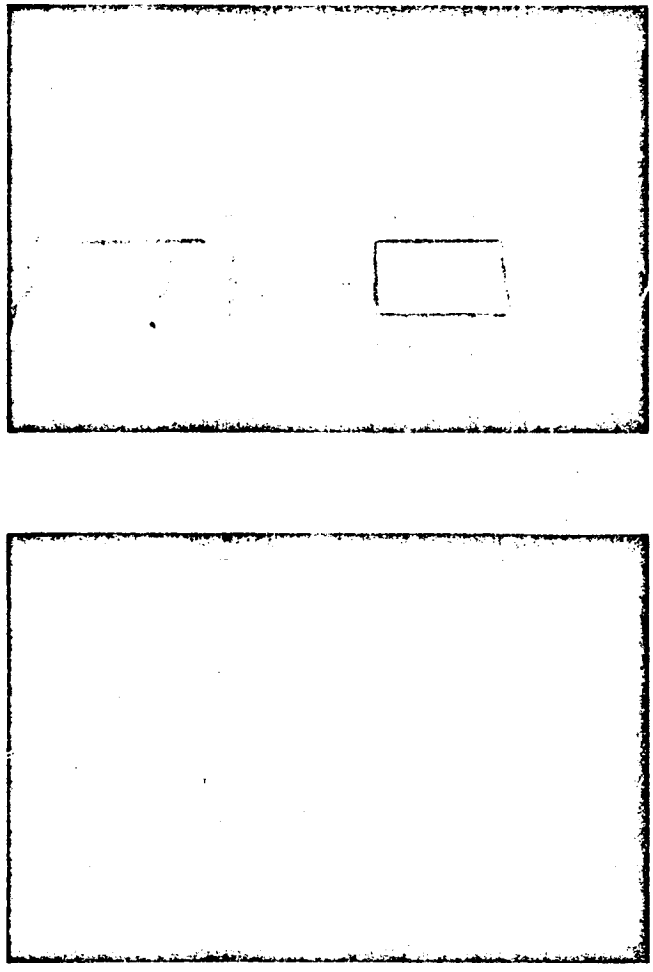


FIGURE 9 PLANCHET TEST CHAMBER CONSTRUCTION

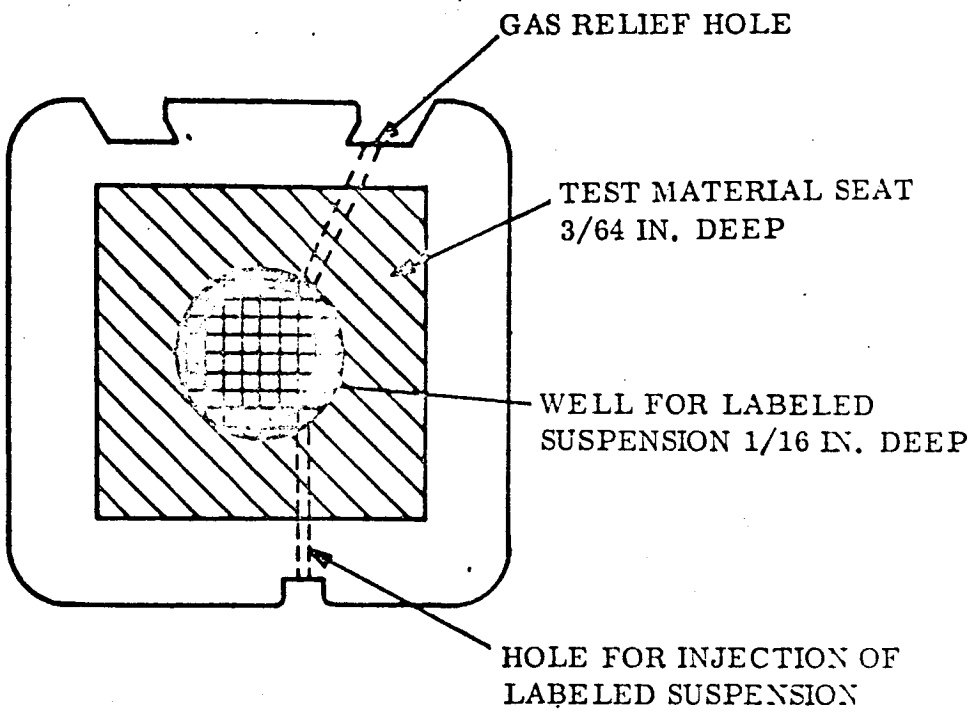


Figure 1. Test Chamber for Permeability of Materials to Microorganisms and Gases

TABLE XIII (CON'T)

Test Material	Background cpm	*CPM (hundreds of thousands)
Armalon	4	1.53
PVC coated fabric	4	1.59
PVC coated fabric	4	1.61
Polyimide	4	1.53
Polyimide	4	1.53
PVC film	4	1.51
PVC film	4	1.53

* .01 ml B. cereus spore suspension

By this method a comparison was made between metallic and plastic surfaces. Also, background measurements could be made on test chambers containing various test materials.

(iii) Absorption Test

After background and backscatter determinations were made, a test chamber containing PVC coated cloth was injected with 2 ml of B. subtilis spore suspension. The chamber was then placed in the detector and adjusted to 4" of water by adjusting the height of the liquid in the plastic tubing.

A second test chamber, containing PVC film, was tested using 2 ml of a suspension of C^{14} labeled M. candidus (Table III). A series of background determinations was made in the same configuration as that used for Ca^{45} labeled B. subtilis.

(iv) Results of Testing

Data from these tests is presented in tables XIV, XV, & XVI.

Material on the order of 17-20 mils could not completely absorb the radiation from Ca^{45}. This has the result of giving a relatively high background. Counting time would be appreciably lengthened if such an energetic isotope were used with material of this thickness.

When internal pressure is applied to the chamber its surface becomes dome-shaped due to the flexibility of the test material Therefore, calculations of detectability cannot be based on a planar surface. Part of the surface will be closer to the detector window, thus decreasing air absorption.

The background rate showed some variations which were probably due to variations in ambient temperature or pressure. Repetition of the Ca^{45} test with both chamber legs open significantly reduced these variations.

The series of background counts made using the PVC film chamber injected with C^{14} labeled Micrococcus candidus was continued over a period of ten days. A rise in activity was seen at the seventh day of testing. This increase is not thought to be due to microbial penetration of the film but to labeled metabolic products and cell constituents. This type of permeation places a limitation on the amount of time a material can be tested in this system. This test will be repeated using a thinner material (5 - 6 mils) to find its permeation time. Further tests will also be run using materials having holes of 1 to 6 microns diameter in order to determine the time required for penetration when holes of known dimensions are present.

TABLE XIV

Background Determinations Using Ca^{45} in PVC Coated Cloth Chamber *

DATE	TIME	CPM
11/2/66	1000	164
	1015	162
	1030	157
	1100	138
	1230	142
	1330	131
	1345	129
	1500	129
	1620	109
11/3/66	0745	106
	0830	112
	0930	112
	1100	151
	1345	140
	1445	137
	1620	144
11/4/66	0800	176
	1010	171
	1130	110
	1525	101

* One leg open to atmosphere

TABLE XV

Background Determinations Using Ca^{45} in a PVC Coated Cloth Chamber *

DATE	TIME	BACKGROUND CPM
11/7/66	1400	112
	1530	111
11/8/66	0830	116
	1230	110

* Two legs open to atmosphere

TABLE XVI

Background Determinations Using C^{14} in a PVC Film Chamber

DATE	TIME	BACKGROUND CPM (60 MIN)
11/10/66	1520	36
	1620	34
11/11/66	0800	26
	0900	27
	1010	29
	1400	28
	1600	28
	0800	36
11/14/66	0800	36
	1430	36
	1600	37
	1700	39
11/15/66	0800	38
	1200	38
	1400	39

TABLE XVI (CON'T)

DATE	TIME	BACKGROUND CPM (60 Min. Count)
11/15/66	1630	39
	1730	39
11/16/66	0750	40
	1000	37
	1240	40
	1440	40
	1540	42
	1640	42
11/17/66	0800	41
	1000	41
	1110	39
	1425	41
	1530	38
11/18/66	0825	41
	1015	39
	1300	39
	1530	41
11/21/66	0800	48
	1000	48
	1400	47
	1500	49
	1600	47
11/22/66	0800	52
	0900	50
	1200	50
	1330	50
	1500	52
	1600	50

TABLE XVI (CON'T)

DATE	TIME	BACKGROUND CPM (60 Min. Count)
11/23/66	0800	52
	1000	54

Conclusions - The use of C^{14} labeled microorganisms in the test chamber gave a much lower background than Ca^{45}. This will yield a much more sensitive testing chamber than the more energetic Ca^{45} when materials on the order of 12-25 mils (density = 30 mg/cm^2) are tested. The background can probably be lowered by shielding of the vinyl filling tubes.

2.5 TASK V - MOCK-UP TEST PROGRAM

2.5.1 Status of the Test Program

The BISS mock-up study program is intended to serve two major purposes:

- Provide an empirical testing to examine the feasibility of operating in the environment peculiar to the BISS concept.
- Provide a means for experimental examination of developing system concepts to support concept development trade-offs.

The majority of the Phase I testing has been completed, and preparations are being made to use the objective and subjective data from these tests to write specifications for the procurement of the Phase II mock-up equipment. The Phase I testing was conceived as early exploratory and equipment development tests aimed at providing data which reflect BISS feasibility, and a data source for specifications for a prime BISS system.

2.5.2 Mock-Up Study Development

The earliest decision in the mock-up study was that of approach, that is: should the study program provide for subsystem tests, each developed in its own context, and meeting downstream in the procurement of mock-up equipment; or should the study program be conducted in two phases, with all subsystems integrating in both phases? The decision was to use the second approach because it was felt that while there is considerable information available about life support and communications systems and protective suits as separate entities, the major unknown in the BISS program is the integration of these subsystems into an operating system for use in the Assembly/Sterilizer. Hence, the earliest goal was to gain experience in the use of these subsystems in a BISS environment, and for this purpose it would be best to have a rudimentary system available as are entity. This rudimentary system could then be examined in detail in the special BISS conditions and a second phase would then serve the purpose of incorporating all of the data and experience gained in the first phase into a more refined system. This second system would then better simulate a prime BISS system and the data from tests on this refined system would more closely reflect ultimate BISS operations. Moreover, this mode of study allows other program developments (fabrix study, bacteriology, physiology, etc.) to develop data which can be used in the second phase and provide additional refinements not possible for the first phase.

The mock-up tests do not require any simulation of BISS sterilization conditions. Instead, the mock-up program aims at the simulation of all BISS conditions outside of strict sterile requirements. For this purpose a chamber had to be procured or modified, and tested for pressurization. For this purpose a 12 x 12 x 20-foot Tenney Altitude Chamber was used and tested in excess of 4 inches of water, outward gage pressure. Figure 6 illustrates the front of the chamber with the hard tube installed.

Simultaneous with these operations, an integrated test plan was written to systematically detail the goals and methods of testing. It was recognized that because of the objective of the testing and the rudimentary nature of the equipment, that objective data alone would not reflect all the important variables to be evaluated. For this reason it was decided to include subjective data and a Subject's Assessment Scale (SAS) was constructed for the purpose.

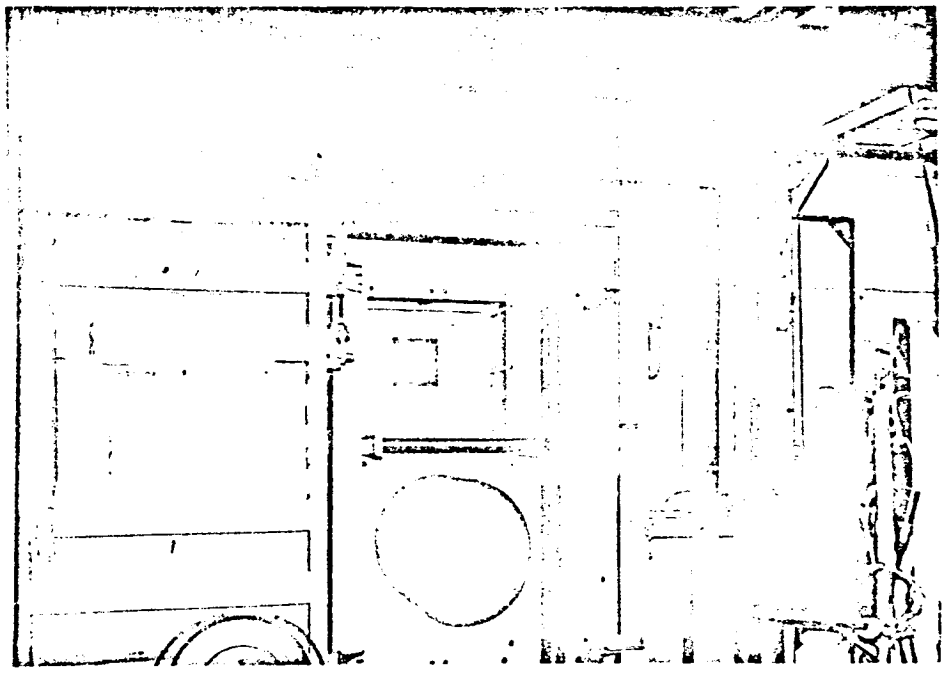


FIGURE 11 FRONT VIEW OF TENNY CHAMBER WITH HARD TUBE AND SAFETY ACCESS DOOR

2.5.3 Phase I Tests

A. Test Summary

In summary, the mock-up effort for Phase I may be viewed as having four constituent parts:

- Mock-up equipment construction - This aspect contains trade-offs and decisions affecting life support equipment; communications equipment; selection, procurement and adaptation of an outer suit/tunnel and helmet; selection, procurement and of an undersuit; hatchway design and construction; integration of all these subsystems into an operating system in the chamber environment; and the selection and orientation of a suitable test subject. Figures 12 through 16 show the mock-up system elements evolved.

- Quantitative tests - This part of the mock-up program contains tests such as obtaining temperatures in the undersuit, humidity measurements, rates of flow of air and water, air and water temperatures, and time measurements of operator/subject operations in suited conditions.

- Qualitative Tests - This area represents use of the SAS to reflect the operator/subject sensations in various phases of operations or conditions of equipment function. In addition, test personnel made observations which were presented to the subject to obtain his evaluative comments. Finally, debriefing sessions were held with all cognizant personnel to evaluate both the qualitative data and their subjective observations, on a daily basis.

- Mock-up improvement - By use of both the qualitative and quantitative data, and the daily debriefing results, immediate mock-up equipment improvements were effected. When required, re-runs of Phase I quantitative or qualitative tests were made after equipment improvements were incorporated.

(1) Tests Performed

The tests which have been performed are listed below. The procedures for these tests are described in the Integrated Test Plan.

(b) Subsystem Tests

(i) Water cooled undersuit

(ii) Air cooled undersuit

(iii) Suit-tunnel leak test

(iv) Outer Suit Fit

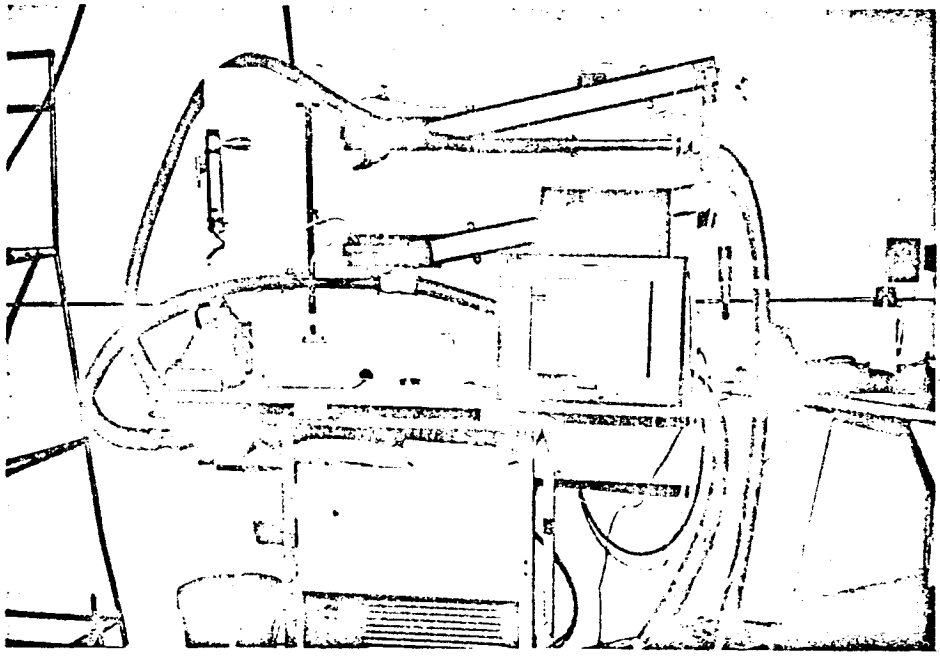


FIGURE 12: PHASE I. LIFE SUPPORT CONSOLE

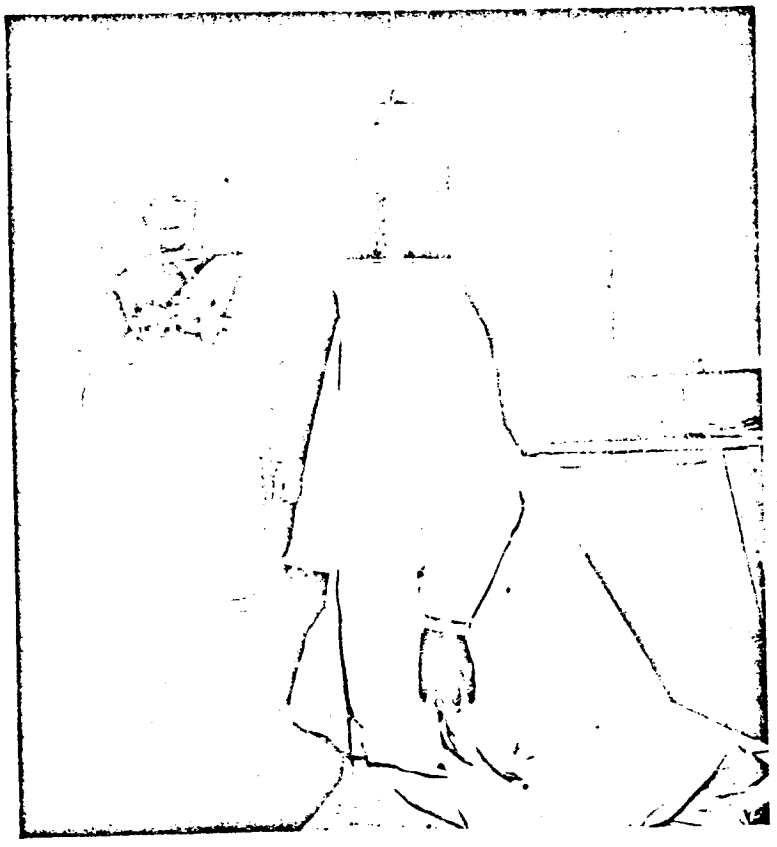


FIGURE 13: PHASE I. AIR COOLED UNDERSUIT AND UNMODIFIED OUTER SUIT

FIGURE 14: REAR VIEW OF AIR-COOLED UNDERSUIT SHOWING LIFE SUPPORT GEAR AND THERMO-COUPLE CONNECTORS.

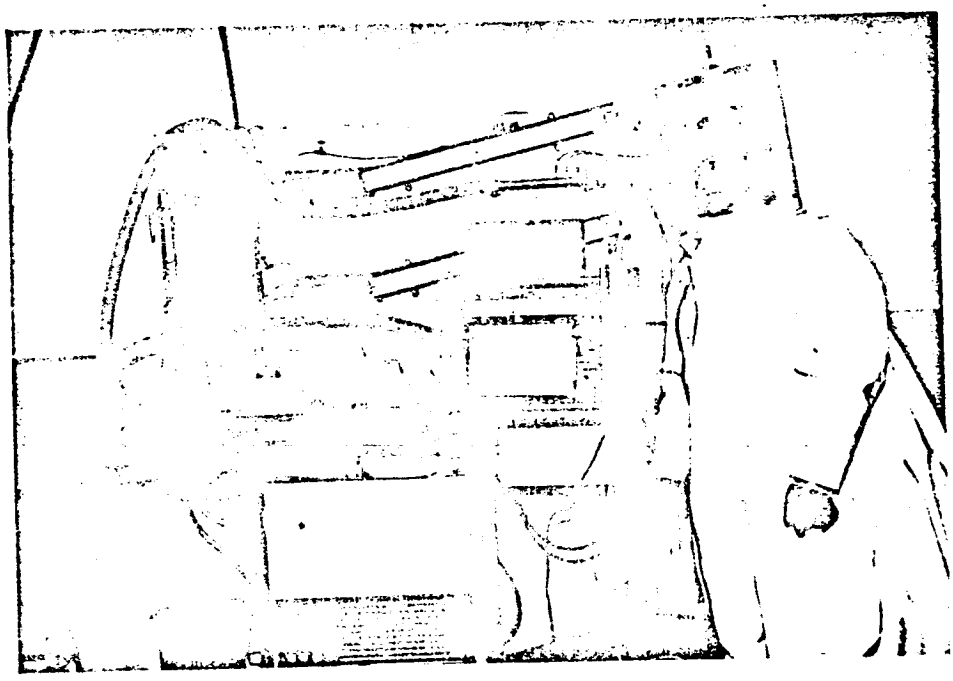


FIGURE 15: SUBJECT IN PHASE I. OUTER SUIT (BEFORE MODIFICATIONS)

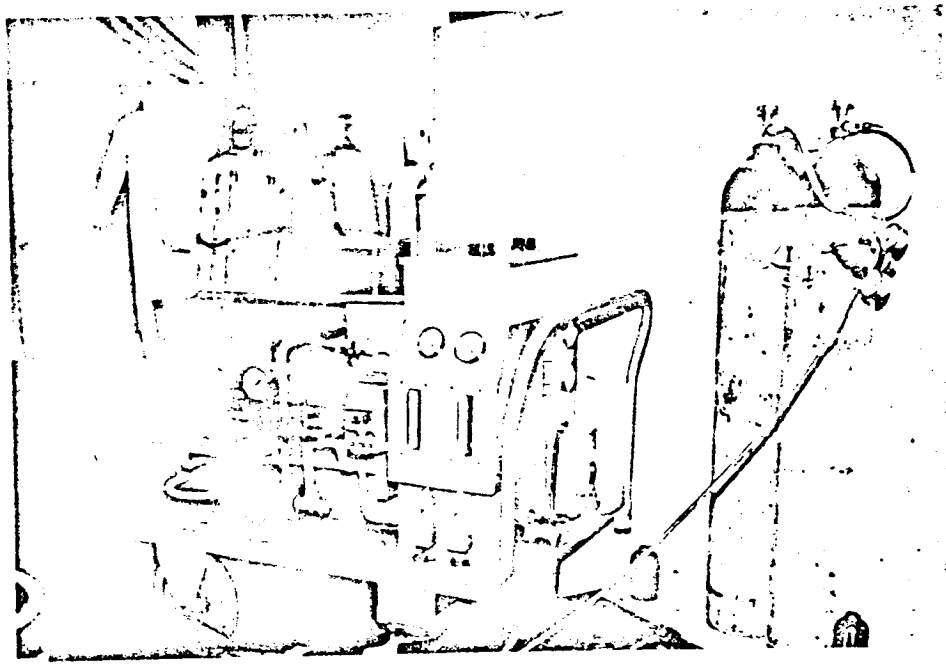


FIGURE 16: WATER COOLED UNDERSUIT
SUPPLY APPARATUS
(THERMAL CONTROL UNIT)

(v) Safety-rescue

(vi) Communications

(c) Suit System Test

(2) Tests Not Performed

The tests not performed and the background are given below.

(a) Helmet Air Supply

The test is intended to measure breathing air requirements and carbon dioxide volume in the helmet of the suited operator. The test was postponed due to a delay in obtaining carbon dioxide measuring equipment in the Phase I time period. The test will be run before the start of Phase II.

(b) Tunnel Reefing

This test is intended to demonstrate the manner in which the tunnel can be positioned to facilitate the entry and exit of the BISS operator to and from the outer suit. This test was not formally and completely run because it was first necessary to observe the effect of the overpressure on the tunnel. Upon making these observations, an attempt was made to reef the tunnel manually through the hatch hard tube. This was found to be impossible and indicated that reefing has to be accomplished within the chamber. Several trials were made of manually reefing the tunnel on the in-chamber portion of the hard tube. This was found practicable, although the difficulty mounted rapidly as the pressure was raised. With this evidence of the practicability of accomplishing such reefing, it is intended that trade-offs of mechanical means will be accomplished prior to the initiation of Phase II.

B. Test Result Summary

The results of the tests performed have been in the form of quantitative and qualitative measurements of the several subsystems and the integrated Phase I mock-up system, and recommendations for components on system alterations. The following summary is equipment oriented to give emphasis to recommendations which results from the tests.

(1) Outer Suit

The outer suit must have relatively straight fit up and down the front so that the overpressure will not compress excess fabric causing forces which inhibit the operator's limb movements. The implication of this is that the BISS outer suit cannot be too deviant from a relatively form-fitting garment and that an adjustment strap

is required for the small amount of deviance that may exist between operators. This adjustment strap should be in the waist-to-crotch area. The further implication is that the operators selected for the ultimate BISS system will have to be rather homogeneous in physical dimensions.

The chamber overpressure compresses the outer suit as it hangs in the donning rack. This makes entry very difficult, especially the initial search for the legs by the operator. The thigh portion of the outer suit has to be stiffened (as was accomplished by rings in Phase I) in order to facilitate suit entry. In addition, stiffening rings are helpful in the arms of the outer suit, (also added in Phase I). Finally, the interface of the outer suit and tunnel requires two relatively close stiffening rings to permit a good tunnel/outer suit - hard tube interface for entry and exit. This was also added in Phase I.

The original concept had the operator entering the outer suit while carrying a helmet mating ring attached to his shoulder harness (yoke). He had to mate the ring with a matching helmet ring for positive support of the helmet. It was found that this mode of operation inhibited easy passage of the operator through the hard tube and that the ring mating was a difficult task because of the tolerance required, the compression of outer suit material in the ring interface area, and the generally limited visibility afforded in the task. For these reasons the helmet, helmet neck ring, and shoulder harness should be part of the outer suit. This requires that the operator enter the shoulder harness and helmet as a unit and then attach adjustment straps for snug fit. Modification of the Phase I mock-up confirmed this improvement.

The shape of the BISS helmet and its material will be important to operational efficiency. If the helmet is too close to the ears of the operator, it will provide for too much sound reverberation and if the helmet possesses too much plasticity it will add to the noise level because the material tends to vibrate with sound. An evaluation of the Apollo helmet made of relatively thin Lexan, as compared to the plexiglass tube-shaped helmet, has revealed these facts. Moreover, the shape of the helmet is important in determining how the air supply is channeled about the interior of the helmet and baffling is required to direct the air flow toward the operator's face (discussed later in this section).

The use of a properly-designed donning rack is vital for satisfactory entry to and exit from the BISS outer suit. Moreover, the manner in which the suit is held and oriented for the operator is critical to the donning operation effectivity. Positive, but quick disconnects are required for the helmet and the four extremities. At the same time, the tunnel-suit interface must fit properly with the hard tube through which the operator exits and enters.

The difficulties of entry and exit operation are very pronounced as overpressure is raised in the chamber. Every chamber-suit operation is practicable at two inches of water pressure, or less overpressure, but difficulty of entry, exit and reefing operations goes up sharply as the pressure is raised from 2 inches to 4 inches of water pressure.

The use of a boom for support of the tunnel is necessary. This takes the load of the tunnel and life support hoses off the suited operator and allows the tunnel to collapse under overpressure in a relatively uniform manner.

(2) Undersuit

The air-cooled undersuit generally appears superior to the water cooled undersuit system for BISS purposes. However, final decision will await additional tests.

The exterior surface of the undersuit must have a low co-efficient of friction to permit easy entry to the outer suit in the outer suit/tunnel/donning rack interface. This requirement poses some difficulty in that the air-cooled undersuit must have elasticity, which usually means use of a rubber material. Since rubber generally has a relatively high coefficient of friction, the use of a talcum powder or silicone spray may be required. This will be examined further in Phase II operations.

The used open-cell foam in a life support garment has shown to be extremely satisfactory. This fact is emphasized because it represents the effectiveness of one of the developmental items for BISS, not common to other suit programs. A satisfactory undergarment that is both comfortable and efficient in life support is especially important to optimization of BISS work cycles and operator work effectiveness.

The fit and hygiene aspects of the undersuit imply that the garment must be a personal garment, fitted to the wearer and worn by no other individual. For the air-cooled undersuit the operator should also wear "long john" underwear to act as the first absorber of skin slough and sweat, and to act as a skin-comfort layer. The use of this underwear will permit ease of laundering and reduce such requirements on the undersuit. To accommodate the donning of the undersuit over the underwear, the innermost layer of the undersuit must also have a low coefficient of friction.

The air-cooled undersuit must act as the interface with the life support gear and the communications equipment. In consonance with the desire to keep all heat-sensitive gear from being attached into the outer suit, the undersuit should be used to transport the required equipment into and out of the outer suit. This objective is supported by the finding that the life support plenum and the speaker/microphone are best located on the undersuit for efficiency in use. The nature of the undersuit requires direct interface with the life support plenum for maximum efficiency. Mounting the

speaker/microphone in the neck/chin area of the undersuit provides good efficiency, easily accommodates body movements, and does not obstruct vision.

The air-cooled undersuit used for the Phase I mock-up was made of 1/16 inch neoprene rubber, to which a very thin layer of dense foam was bonded, with 1/4 inch thick open-cell foam (10 pores per linear inch) on the inner-most surface. The suit was fashioned on the general lines of a SCUBA suit with a long torso zipper and a short zipper at each extremity, to facilitate donning and doffing the suit. The mock-up study has demonstrated that the relatively close fit of the suit was too restrictive and that while the Phase II suit must also be form-fitting, it should be lighter and not as snug fitting. The 1/16 inch neoprene is too heavy and can be replaced by neoprene as thin as 1/64 inch to retain elasticity while reducing weight.

(3) Tunnel and Hatch

Simple, manual reefing through the hard tube is impossible. Moreover, no very simple method of reefing appears practicable. While manual reefing of the tunnel onto the hard tube in the chamber has been repeatedly accomplished under a variety of overpressures by two men, the manner by which this can be accomplished mechanically is not simple.

A means is required to prevent the tunnel from being pushed by the the overpressure into the hard tube. This has been accomplished by putting a "piston" into the hard tube after the operator has entered the outer suit. This close-fitting object is placed at the chamber end of the hard tube so that the tunnel is not pushed into the tube as the operator walks out into the chamber and the tunnel collapses behind him. The smooth, rounded surface of the piston also provides some spreading effect as the tunnel is reefed back onto the hard tube.

The hard tube is necessary to facilitate entry to and egress from the outer suit and acts as an interface with the outer suit as it is held in the donning rack. While the mock-up study uses a circular hard tube, the ultimate tube should have parallel sides with semi-circular ends, much like a standard watertight door in ships. At the outside of the chamber the hard tube can be flush with the chamber, but on the inside of the chamber, the hard tube must be of a length sufficient to permit reefing of the tunnel.

After the tunnel collapses behind the suited operator, mobility of the operator in the chamber is good, regardless of overpressure. With the use of a boom to support the tunnel by way of stringers, the tunnel collapses along its horizontal length and easily follows the operator as he moves about. At the same time, the life support hoses and communications line are held up by the boom and stringers, permitting good in-chamber mobility. The reefing of the tunnel requires a spreader which spreads the tunnel out against the overpressure and allows it to be drawn back over the hard tube. This spreader will have to be integrated with the reefing technique so that the total reefing process will be a rapid, easy operating system.

(4) Life Support

The suited operator must have the sensation of a cooling effect in the helmet. It is not sufficient that the operator is simply fed cooling and breathing air in the helmet, he must be able to feel this air blow across his face. This sensation of air flow appears necessary for psychological comfort and a sense of "real" cooling. Having the knowledge of cooling/breathing air being available is apparently not enough. Therefore, the Phase II helmet will contain this concept within its design, while the Phase I helmet accomplished it by air-tube supply positioning.

Within limits, the undersuit exhaust system appears to be paramount in importance for comfort, more so than the temperature of the cooling air. That is, changing the cooling air temperature from 70°F to 65°F does not appear to effect a cooling sensation for the operator as much as changing the exhaust flow from 5 cfm to 10 cfm. This became apparent soon after the fact that the subject began to ask for increased exhaust flow rather than cooler air as work load went up.

Humidity "control" in the form of a definite humidity range requirement is necessary to prevent lip drying. This was evident in the use of both the water-cooled and air-conditioner life support systems, (Phase I solved the air conditioner system problem by putting humidity into the air supply). Phase II will study the problem more extensively. At the same time, this fact has revived the possibility of introducing potable water into the suit for the operator to use, as required.

(5) Monitoring

Respiration measurement by means of a cardiac microphone placed on the operator's chest is unacceptable. The respiration communication is drowned out by speech and body movements of any sort. The signal is audible only when the operator is standing very still and quiet. Therefore, this method is extremely limited and useless for BISS goals.

The suited operator's verbal remarks are more useful for life support purposes than is any feedback in the form of displays. The verbal remarks reflect real time information while the displays require time to reflect changes in the system. For this reason verbal communication becomes primary as a source of work information, life support information and requests, and safety information.

(6) Communications

The original concept of the use of a single channel to and from the in-chamber operator is unacceptable. This is important because it has been shown that the sound levels required in the helmet and at the test conductor's console are different, and because a dual channel cuts down on the need to repeat messages while aiding in

rapidity of information processing and understanding. Duplex communication is not especially necessary for other channels (e.g. test conductor to life support console operator).

The in-chamber speaker is a satisfactory back-up for regular operator-test conductor communications. Experience with this form of back-up has indicated that the suited operator can use information from such a speaker in the event his primary communication system fails. However, such a back-up is only a temporary measure and requires that the regular communications channel be repaired as soon as possible.

The shape of the helmet is important to good communications. Helmet shape can affect reverberation and produce poor understanding of information. Moreover, the material from which the helmet is made is important, in that a material that has too much plasticity tends to act as a vibrating membrane and increases reverberation.

(7) Miscellaneous

The mock-up study has accrued approximately seventy-five (75) hours of suited operator overpressure experience in the chamber. Moreover, there have been many hours in the chamber without overpressure. This experience has enabled the program personnel to obtain a good appreciation for problems in the overpressure environment and to make valuable comparisons with ambient operating conditions. A general remark on the overpressure experience, to date, would be that the central problem involved with a BISS overpressure environment is in reefing and entry/exit conditions, and that having accomplished these requirements, the suited operator has few problems in subsequent operations in the chamber. The second general remark has to do with the nature of suited operations, in that the greatest effectiveness will be derived if the in-chamber operations are tailored to the requirements peculiar to a suited operation. The in-chamber operations will have to be pre-planned in detail so that specific operations are completely analyzed and executed, to permit the maximum operator involvement with the greatest efficiency and least error.

From the few subjects who have been either interviewed and/or selected for use in the mock-up study, it is apparent that selection of ultimate BISS operato , apart from size and general capability, will be on the basis of physical and psychological factors. Aside from being physically fit and free from any ailment symptoms of any kind, the operator should be free of personality traits which would tend to promote anxiety or apprehension in a BISS environment. For this reason, psychiatric tests will have to be administered in addition to physical tests. Both types of tests will have to be of more than common severity and depth; with periodic repetitions, as required. At the same time the BISS operator will have to be a serious, careful individual who can integrate in chamber operations very well, since team cooperation and personality assimilation will play an important role in maximizing work efficiency.

SECTION 3

ACTIVITY PLANNED FOR NEXT THREE MONTHS

3. ACTIVITY PLANNED FOR THE NEXT THREE MONTHS

The activity planned on each of the five program tasks for the next three months is described below.

TASK I SYSTEM CRITERIA

No activity is planned on this task except incorporation of new or changed data as a result of the program studies on the other four tasks.

TASK II CONCEPT DEVELOPMENT

The concept developement effort will continue in each of the technical areas with emphasis on refining the evolving system concept. Particular emphasis will be placed on investigations of bio-integrity and leak detection; suit, tunnel, and helmet configuration; reefing schemes; and use of an antechamber.

TASK III INTEGRATED TEST PLAN

No activity is planned on this task beyond preliminary test planning for a prime BISS system.

TASK IV MATERIALS ANALYSIS

The data search on materials will be completed. Physical testing of materials will progress in accordance with the test plan schedule. Fungus testing, and microorganisms and gas permeability testing on virgin materials will be essentially completed, as will disinfection testing and tests of the compatibility of materials with disinfectants and detergents.

TASK V MOCK-UP TEST PROGRAM

The Phase I mock-up tests will be completed. The Phase II mock-up system will be designed and procured. Preparations will be made to initiate the Phase II tests upon receipt of the suit/tunnel, undersuit, and helmet.

SECTION 4

PROBLEM AREAS

4. PROBLEM AREAS

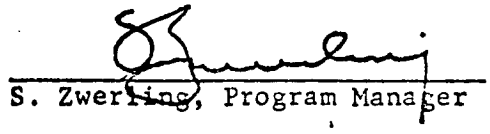
No problems have occurred on the program to date and none are foreseen.

APPENDIX A

BIO-ISOLATOR SUIT SYSTEM

CRITERIA

Prepared Under NASA Contract NAS 1-6537
for Langley Research Center
& Langley Station
Hampton, Virginia 23365



S. Zwerling, Program Manager

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Re-Entry Systems Department
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BIO-ISOLATOR SUIT SYSTEM

CRITERIA

1. Scope This document defines the system criteria to be employed in the design and analysis of the Bio-Isolator Suit System (BISS).

2. Applicable Documents

The following documents of the issue listed are applicable to the extent specified herein.

2.1 National Aeronautics and Space Administration

NASA SP3006 Bioastronautics Data Book 1964

2.2 The Chemical Rubber Co.

46th Ed. Handbook of Chemistry and Physics 1965-66

2.3 American Conference of Governmental Industrial Hygienists

Threshold Limit Values for 1965

2.4 John Wiley and Sons Publishers

Keenan and Keyes, "Thermodynamic Properties of Steam," 1936

3. Requirements

3.1 Configuration The basic configuration requirement is that the BISS system provide capability for a technician to work in a sterile chamber while maintaining absolute biological and topological isolation of the technician from the environment.

3.1.1 Equipment Complement. The general configuration of the BISS shall be consistent with that shown in Figure 3.1. The BISS system shall consist of the following (see also section 4.0):

- BISS Suit and Tunnel
- Life Support Subsystem
- Hatch
- Communication Subsystem
- Ancillary Equipment

3.1.2 Shape and Size

The BISS suit shall be anthropomorphically shaped and shall accomodate male operators of the 30th (67.7", 154 lb)* through the 80th (71.4", 195 lb)* percentiles.

3.1.3 Mobility The BISS shall permit good freedom of movement of the technicians body and extremities with minimum forces on the technician. The technician shall be able to move and work throughout a semicircular area with a 60 foot radius centered at the hatch. A 20 foot vertical ascent capability shall be provided except that a line from the hatch center to the center of the tunnel/suit interface need not exceed an angle of 45^{o} from the horizontal. The system shall provide maximum facility for entry to and egress from the suit.

3.2 Bio-Integrity

The BISS suit and tunnel shall maintain a positive barrier between the sterile chamber and their inside surfaces. They shall be impervious to puncture, rupture, tear, or any other failure which would violate the barrier.

The BISS shall have less than 1 chance in 10^{5} of permitting microbial penetration to the sterile area. (Analytical or experimental substantiation of the satisfaction of this requirement is beyond the scope of this program).

3.3 Technician Environment

The BISS system shall provide a healthful, comfortable environment for the technician in the suit performing light manual labor. As a minimum the system shall provide control of:

- Composition of gases breathed and in contact with the body (including removal of noxious or toxic gases)*[1]
- Humidity of gases breathed and in contact with the body.*[1]
- Temperature of gases breathed and in contact with the body.*[1]
- Suit pressure

* Subject to revision

*[1] In the event that the use of a water-cooled under garment is selected, these criteria will be appropriately ammended.

Control of these parameters shall be achieved primarily by providing facilities and equipment for conditioning and distribution of ambient atmospheric air.

3.3.1 Standard Atmospheric Composition

The standard composition of atmospheric air to be used for the study and design of the BISS system shall be that defined in the Chemical Rubber Company's 46th Edition of the "Handbook of Chemistry and Physics" (pg F116). The breakdown of this composition (exclusive of water vapor) is given in Table 3.1.

The water vapor concentration standard (by volume) for the study and design of the BISS system shall be that defined in Table 3.2 derived from equation 12 of Keenan and Keyes, "Thermodynamic Properties of Steam," John Wiley and Sons, 1936.

TABLE 3.1

COMPONENTS OF ATMOSPHERIC AIR
(Exclusive of water vapor)

CONSTITUENT	CONTENT (%)	CONTENT (PPM)
N_2	78.084 ± 0.004	
O_2	20.946 ± 0.002	
C_2	0.033 ± 0.001	
A	0.934 ± 0.001	
Ne		18.18 ± 0.04
He		5.24 ± 0.004
Kr		1.14 ± 0.01
Xe		0.087 ± 0.001
H_2		0.5
CH_4		2.0
NO_2		0.5 ± 0.1

TABLE 3.2

WATER VAPOR CONCENTRATION AS A FUNCTION OF RELATIVE HUMIDITY
(For a 760 mmHg Atmosphere)

TEMPERATURE (Degrees F)	PERCENT BY VOLUME FOR RELATIVE HUMIDITIES AS GIVEN									
	10	20	30	40	50	60	70	80	90	100
50	0.12	0.24	0.36	0.48	0.61	0.73	0.85	0.97	1.09	1.21
60	0.17	0.35	0.52	0.70	0.87	1.05	1.22	1.4	1.57	1.74
70	0.25	0.49	0.74	0.99	1.24	1.48	1.73	1.98	2.22	2.47
80	0.34	0.69	1.03	1.38	1.72	2.07	2.41	2.76	3.10	3.45
90	0.48	0.95	1.43	1.9	2.38	2.85	3.22	3.8	4.28	4.75
100	0.65	1.29	1.94	2.58	3.23	3.88	4.52	5.17	5.81	6.46

3.3.2 Breathing Gas Composition Limits

The standards for gas composition limits for the BISS environment shall be in accordance with the "BIOASTRONAUTICS DATA BOOK," NASA SP-3006, and the Threshold Limit Values published by the American Conference of Governmental Industrial Hygienists.

3.3.2.1 Oxygen

Oxygen concentration shall be between 17 and 36 percent by volume (1.2 of Bioastronautics Data Book (BDB)) with a nominal objective of 21%.

3.3.2.2 Carbon Dioxide

Carbon Dioxide concentration shall not exceed 0.5% by volume (1.5 of BDB).

3.3.2.3 Nitrogen and Inert Gases

No absolute limits are established on concentrations of nitrogen and the inert gases. However, it is the objective that these gases approximate the standard compositions of Table 3.1.

3.3.2.4 Noxious and Toxic Gases

The concentrations of all gases shall be maintained below the noxious or toxic limit, whichever is lower. The toxic limits shall be in accordance with the American Conference of Governmental Industrial Hygienists Threshold Limit Values (TLV) where TLV are specified for the gas in question. "The Threshold Limit Values refer to airborne concentrations of substances and represent the upper limit of conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effect."* Specific gases which present a potential hazard to be guarded against in the BISS system are given in Table 3.3 along with TLV or comments on concentration.

*TLV 1965 p. 1

TABLE 3.3

GAS CONCENTRATION HAZARD LIMITS

Gas	TLV PPM	Comments
CO_2	5000	
N_2	*	Simple Asphyxiant
H_2S	20	Hydrogen Sulfide
H_2	*	Toxic hazard slight. Explosive range 4.1% to 74.2% in air
CH_4	*	Methane-similar to H_2
$(CH_2)_2$	50	Ethene
$(CH_2)_2O$	50	ETO
Cl_2CF_2	1000	Freon 12

* TLV not defined

Noxious gases and vapors shall be maintained at concentrations sufficiently low that they are not offensive to the technician in the suit. If the presence of any significant quantities of noxious gases or vapors is encountered in the mock-up program and is considered characteristic of the system; this requirement will be quantified to define, for these gases, maximum concentrations which are not offensive to the technician.

3.3.3 Body Contact Gas Composition

Any gas mixture supplied for body cooling shall be of the same composition as that used for the supply of breathing gas. Without exception, any gas mixture safe for breathing presents no cutaneous hazard.

3.3.4 Gas Distribution

Gas supply for breathing shall be directed to the face or head area and shall not flow over body surface areas enroute to the face. If gas body cooling is employed, both breathing and cooling gases may be supplied by a common line to the suit, but must be distributed independently at the suit. Active purging of the suit and helmet shall be employed to prevent buildup of noxious or toxic gases.

3.3.5 Skin Contact Materials

All materials employed in the system in contact with the skin of the technicians shall be materials which have histories of acceptable use in contact with the skin without causing irritation. In no case shall a material be employed which has a history of causing acute or extended irritation in any significant percentage of the population or has caused chronic ailments in otherwise healthy adults. Whenever possible, materials used in contact with the skin shall be materials which have been previously approved by the F.D.A. for medical applications for skin contact or body implantation.

3.3.6 Temperature/Humidity

The BISS System shall provide control of the temperature and humidity of the environment in accordance with the following subparagraphs. If an air cooled under suit is employed, para. 3.3.6.1 applies to both breathing and body cooling gas, and para. 3.3.6.2 does not apply. If a water cooled under suit is employed, para. 3.3.6.2 applies to body cooling.

3.3.6.1 Air Cooling

The nominal environment inside the suit at a gas flow rate of 15 to 25 fpm shall be a dry bulb temperature of 77°F at a relative humidity of 40%. (This is an effective temperature of 70.5°F.) The dry bulb temperature tolerance of the supply shall be ± 1.5°F. around a set point adjustable from 66.5 to 78.5°F. Relative humidity of the supply shall be between 30 and 50% (at dry bulb of 77°F this gives and ET of 69.5 to 71.5°F).

3.3.6.2 Water Cooling

The nominal environment of the inside of the suit shall be a dry bulb temperature of 70°F with no appreciable air flow. The water cooling supply tolerance shall be ± 1.0°F around a set point adjustable from 60 to 80°F. Relative humidity shall be maintained less than later percent by active gas scavenging. This will require a gas supply to prevent excessive negative pressure.

3.3.7 Gas Flow Rate

The nominal gas flow rate shall be later fpm in the suit. Air flow rate tolerance shall be ± 5 fpm around the nominal. The air supply volume requirement shall be on the order of later cfm (specific value to be determined by the supply rate necessary to achieve the prescribed linear flow velocity).

3.3.8 Biological Environment

See Hygiene, Section 3.6

3.3.9 Pressure

The suit system shall be at a nominal pressure of 760 mmHg with a pressure differential across the outer suit and tunnel of up to 4" of water gage (7.5 mmHg) inward.

3.3.10 Water Supply

Later

3.4 Technician Safety

The highest priority in the design of the system shall be given to the safety of the suit occupant. This shall include, as a minimum, reliability of the life support equipment, protection of the occupant from physical injury, provision for rapid emergency egress from the suit (aided or unaided), and provisions in the facility operating plans to maximize the protection of the suit occupant.

3.4.1 Life Support Reliability

The life support system shall have a probability of not less than .99 of providing a safe operating environment for the operator during any working shift (see also Endurance, section 3.8). The safe environment shall be that defined in section 3.3 above.

3.4.2 Life Support Backup

A back-up gas supply shall be provided to maintain a safe breathing environment for the suit occupant in the event of life support system failure. This system shall have sufficient capacity to support the suit occupant for a period of not less than 20 minutes (fifteen minutes planned maximum plus five minutes reserve). *

*Subject to revision depending upon experience in satisfaction of the requirements of paragraph 3.5.1.

3.4.3 Physical Protectors

As a minimum, the suit shall provide protection of the head, face, and feet from sources of injury such as falling objects. In addition, the BISS materials, construction, and operating instructions shall be designed and selected to minimize the potential of rips, tears, punctures, or cuts.

3.4.3.1 Helmet

The helmet shall include "hard hat" provisions equivalent to an industrial safety hat and a safety faceplate providing protection from flying objects equivalent to the protection provided by safety glasses.

3.4.3.2 Boots

The boots (or under shoes, if used) shall incorporate safety caps to protect the toes and arch from dropped objects. The outer soles of the boots shall be of non-skid construction to minimize the hazards of slipping or falling.

3.4.4 Safety Checking and Monitoring

Checking and monitoring of the environment of the BISS and monitoring of the physiological response of the operator to the environment and working conditions shall be performed to assure operator safety. Automatic alarms shall be provided to bring attention to hazards or abnormal personnel conditions. The measurements of table 3.4 shall be provided and shall incorporate alarms.

TABLE 3.5 SAFETY MONITORING

PARAMETER	FREQUENCY	ALARM LIMIT
Toxic gas concentration (notes 1 & 2)	Continously during occupancy	TLV (table 3.2)
Oxygen Concentration	"	17% min., 36% max. by volume
CO_2 "	"	.5% by volume
Respiration rate	(Later)	(Later)
Pulse rate	(Later)	(Later)

NOTES: (1) Gases to be monitored shall be those toxic gases found to be characteristic of system performance (if any).

(2) ETO concentration shall be measured at least after each ETO cycle.

3.4.5 Material Flammability

The suit and tunnel shall be constructed of material which is non-flammable or will not support combustion (materials shall be capable of passing applicable ASTM standard test or equivalent).

3.4.6 Emergency Procedure

Procedures and/or facilities shall be provided to permit rapid egress of a conscious occupant from the suit or rapid removal of an unconscious occupant. Three classes of emergency conditions are defined in Table 3.5 with appropriate procedural criteria.

TABLE 3.5

BISS EMERGENCY CLASSIFICATIONS

Class	Conditions	Procedural Criteria
I	Loss of breathing gas supply Major system leak Toxic gas exceeds TLV	Activate emergency gas supply Operator may complete immediate task Operator shall be clear of the suit within 15 minutes
II	Loss of temperature control	Operator may complete immediate task Operator shall leave the suit if suit temperature goes below 60°F or above 100°F.
III(a)	Operator sustains physical injury	Operator shall be removed from the suit within 4 minutes and shall then receive immediate medical attention (a respirator shall be available)
(b)	Operator faint or unconscious Operator heart failure Operator respiratory failure Operator stroke	Activate emergency oxygen Operator shall be removed from the suit within 2 minutes (objective - 4 minutes requirement) and shall then receive immediate medical attention (a respirator shall be available)

3.4.7 Electrical Safety

The BISS System and operating procedures shall be designed to prevent accumulation of static electricity which would cause a discharge between the BISS suit or tunnel and any grounded object in the A/S.

The BISS system shall electrically insulate the occupant from any unprotected electrical contacts in the A/S.

3.4.8 Standard Operating Procedures

The operating procedures for the BISS in the A/S shall be designed to maximize protection of the BISS suited operator. Specific procedural criteria are:

- When a man is in the BISS suit, there shall always be at least one other man in the chamber to provide any necessary assistance. Work plans and detailed layout shall be designed so that physical restrictions of mobility do not limit one man from being able to assist his nearest co-worker in the chamber.

- The environment and BISS occupants' response to the environment shall be continously monitored by personnel trained to interpret the observed data and initiate any immediate corrective action required.

- Personnel shall be available outside the chamber to render any necessary assistance for routine or emergency entry or egress.

- A test director or coordinator shall observe all BISS operations in the Assembly/Sterilizer. He shall be responsible for the direction and coordination of all emergency activity and shall determine when and if system bio-integrity must be broken to rescue a BISS occupant.

- Trained medical personnel shall be on call at all times when personnel are in the BISS suits. These personnel shall be able to reach any BISS hatch with necessary emergency equipment within two minutes of being called.

- All personnel shall receive a medical examination prior to the start of the work shift.

3.5 Human Factors

The system shall be designed to high standards of human engineering practice. Where applicable the Bioastronautics Data Book, NASA SP3006, will be used as the primary baseline of human factors data.

3.5.1 Entry and Egress

The design shall provide maximum ease of entry to and egress from the suit through the tunnel. The tunnel shall be longitudinally contracted (or reefed) during entry and egress. Specialized equipment required to aid entry or egress shall be considered as part of the BISS system.

The maximum times alloted to routine entry to,and egress from, the suit shall not exceed 15 minutes with 5 minutes as a design objective. The times for emergency egress are defined in table 3.5.

It is intended that the requirement for routine entry and egress be satisfied with the suit occupant unaided by other personnel. Assistance by personnel inside the sterile chamber shall not be employed for routine entry and egress.

Entry and egress times defined herein include the time required to extend or contract the tunnel.

3.5.2 Work Shift Duration

The BISS system shall permit a four hour period without interruption. It is an objective that the system permit an eight hour work shift in two four-hour periods with a break for rest and eating between periods.

3.5.3 Occupant Comfort

In addition to the provision of an environment in accordance with Section 3.3, the system design shall provide the maximum possible comfort for the occupant. Suit parameters applicable to this criteria are: types and locations of padding, suit stiffness, freedom of movement, magnitude and location of suit weight bearing points, unbalanced hydrostatic pressures, etc.

3.5.4 Visibility

The design shall not limit the vision of the occupant either by obstruction of visual field or by aberration. The visual field with the head upright and facing forward shall be not less than $\pm$ 110° in the horizontal plane and not less that + 60°, - 80° in the vertical plane. The helmet and face plate shall be so designed that this visual field relative to the head is maintained when the neck is subjected to the ventral and dorsal flexions and right and left rotations of paragraph 3.5.5. Provision shall be made to prevent fogging of the face plate. The design shall accommodate the wearing of eyeglasses.

3.5.5 Mobility

The design shall permit maximum mobility of the suit occupant consistant with the other system criteria. The occupant shall be capable of movement throughout a semicircular region with a radius of 60 feet, centered at the hatch. A twenty foot vertical ascent capability is also required. (Practical limitations of suit and tunnel support may limit ascent with the tunnel fully retracted; however, as a minimum, the system should provide ascent capability equal to the radial distance to the hatch center in a plane parallel to the floor, up to a maximum of 20 feet ascent (i.e., half cylinder of 60 foot radius and 20 foot height with a 45° half cone removed).

The BISS system shall provide as a design goal no more than 10% decrement in the joint motions, and as a requirement no more than 25% decrement. Joint motions for most body joints are defined in Figure 3.2. In addition, the following normal neck motions are defined:

. Ventral flexion.	60° Mean	12° S.D.
. Dorsal flexion	61	27
. Right or left flexion	41	7
. Right or left rotation	79	14

The system design shall also specifically provide maximum unrestricted capability for:

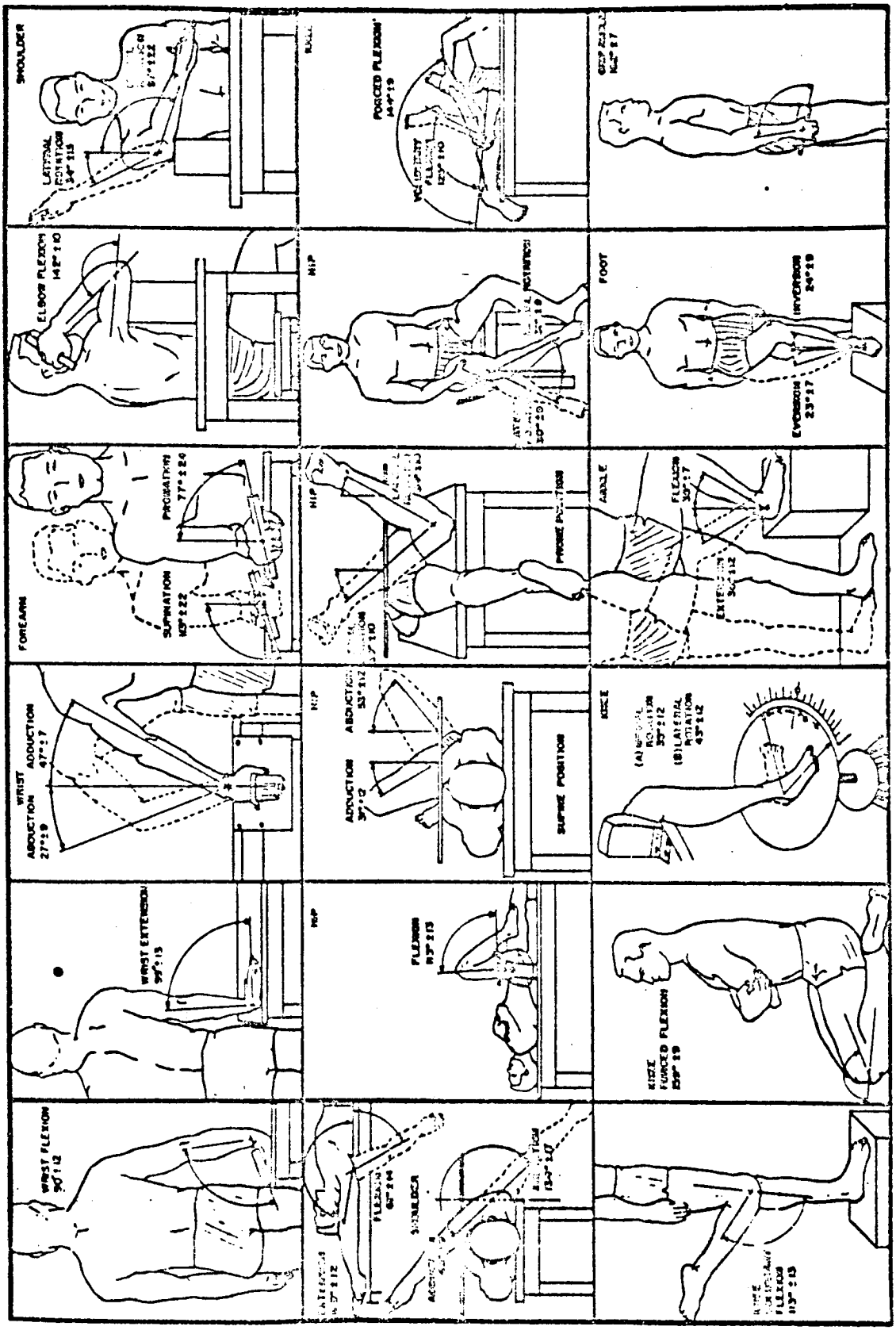
- 45° forward bend at the waist
- Squatting
- Scaffold or ladder climbing
- Walking

3.5.6 Manual Dexterity

The BISS system shall provide for maximum technician finger and hand dexterity compatible with overriding criteria such as bio-integrity and safety. Manual tasks to be considered in assessing dexterity are:

- Use of common hand tools
- Fastener starting
- Modular assembly operations
- Connector mating and demating operations

JOINT MOTION



Ranges of joint motion in 39 young men, showing the median value in degrees, ± 1 standard deviation. If ± 2 SD are taken, 95% of the sample of 39 is included. Compared with the 1950 Air Force survey of over 4000 flying men, this sample is 6.8 years younger, 6.0 lbs heavier, and 1.4 inches taller.

Source: Adapted from analysis by Barter et al. [2] of data from Dempster [13].

Fig. 3.2

(Source for present document: BIOASTRONAUTICS DATA BOOK, NASA SP30006, 1964)

3.5.7 Communications

The BISS system shall provide aural communication between suit occupants and between a suit occupant and control or support personnel through the use of an electrical or electronic communications system. A system of hand signals can be employed for back-up in the event of communications system failure. However, as a minimum, this shall be augmented by a signalling system incorporating the following:

- A panic button in or on each suit to draw immediate attention of control personnel to a suit occupant who needs assistance or has lost aural communication.

- A sounder or light in the helmet of each suit to draw immediate attention of suit occupant to hand or other visual signals from control personnel.

The following additional back-up communications equipment shall also be considered for employment in the Assembly/Sterilizer - BISS:

- A loud speaker system in the A/S main chamber with sufficient power capability to create an audible, intelligible voice signal in the BISS helmet.

- Flexible diaphrams in the BISS helmets to permit direct, short distance voice communications between BISS operators.

3.5.8 Suit Fit

The BISS suit shall be designed to provide a comfortable fit for the 30th to 80th percentiles of American adult males. If necessary, the suit fit shall be adjustable to accomplish this capability. To the maximum extent possible within these limitations, the suit shall be form fitting with a minimum of protruding bulges or folds of suit materials. Folds necessary to accomodate the smallest acceptable occupant in the suit shall be so designed and located as to minimize the hazard of snagging.

3.6 Hygiene

The BISS system design and operating procedures shall incorporate provisions for interchange of suit occupants with a minimum of delay without presenting offensive or unhygienic conditions for the second occupant.

The BISS system will employ an appropriate under-garment, or inner-suit, so that an occupant leaving the suit takes with him as large a percentage as possible of the microbial life he produced or liberated during occupancy.

Following egress of a suit occupant, the suit interior will be sanitized and disinfected to remove or inactivate any significant residual microbial life from the occupancy. *The procedure shall require less than 30 minutes to perform and shall consist of at least the following:

- Sanitize - Clean with detergent solution and rinse
- Disinfection - Spray or wipe with a suitable disinfectant
- Rinse - to remove residual disinfectant if necessary
- Dry

This procedure shall render the suit physically clean and will destroy potentially pathogenic organisms. The organisms of primary concern are:

- Mycobacterium tuberculosis
- Staphylococcus spp
- Streptococcus spp
- Candida albicans
- Pathogenic fungi
- Respiratory viruses

The disinfectant used shall be non-toxic and non-noxious or the procedures for operation shall provide for removal to the extent that residual concentrations in the suit material and suit atmosphere are below toxic or noxious limits. If they are not inherently non-toxic and non-noxious, maximum acceptable concentrations shall be defined and added to paragraph 3.3.2.4.

3.7 Equipment Environment

3.7.1 Outside A/S Main Chamber

The environment outside the A/S main chamber shall be assumed to be a minimally air-conditioned industrial environment for both operating and non-operating conditions.

3.7.2 Inside A/S Main Chamber

In addition to cleaning of the suit and tunnel outer surfaces in the same manner as described in paragraph 3.6 for inner surfaces, the suit and tunnel will be exposed to the four environmental modes of the Assembly/Sterilizer chambers as described below. The BISS system is operational in the modes of paragraphs 3.7.2.1 and 3.7.2.4 and non-operational in the modes of paragraphs 3.7.2.2 and 3.7.2.3.

*Subject to revision based on continuing study of hygiene.

3.7.2.1 Maintenance and Transfer - AIR

*. Class 100 vertical laminar flow of 90 ± 15 fpm

. Atmospheric air

. Temperature of 75 ± 5°F

. RH less than 90%

. Pressure - ambient

3.7.2.2 Decontamination - ETO/FREON

*. Class 100 vertical laminar flow of 90 ± 15 fpm

. ETO/FREON (12%/88% - W/W)

. Temperature of 70 to 150°F

. RH of 40 to 60%

. Pressure up to 4" H_2O gage

3.7.2.3 Sterilization - Nitrogen

*. Class 100 vertical laminar flow of 90 ± 15 fpm

. Nitrogen

. Temperature of 70 to 320°F

. RH less than 1% above 200°F

. Pressure up to 4" H_2O gage

3.7.2.4 Operation - Nitrogen

*. Class 100 vertical laminar flow of 90 ± 15 fpm

. Nitrogen

. Temperature of 75 ± 5°F

. RH of 20 - 50%

. Pressure up to 4" H_2O gage

---

* Subject to revision based on future consideration of the need for laminar flow in the Assembly/Sterilizer facility.

3.7.3 Inside Suit and Tunnel

When the Assembly/Sterilizer system is in the modes of paragraphs 3.7.2.1 and 3.7.2.4 above and the operator is in the suit, the environment shall be in accordance with technician environment defined in section 3.3. When the system is in these modes, the suit and tunnel inner surfaces may be exposed to the cleaning procedure described in section 3.6.

When the system is in the modes of paragraphs 3.7.2.2 or 3.7.2.3 or is unoccupied in the modes of 3.7.2.1 and 3.7.2.4, the environment in the suit and tunnel will be air of atmosphere composition at nominally the same temperature as the main chamber gas. If this gas mixture produces degradation of the materials or equipment inside the suit and tunnel at elevated temperatures of the modes of 3.7.2.2 and 3.7.2.3, the suit can be filled with nitrogen in these modes.

The pressure inside the suit and tunnel will be at nominally atmospheric pressure at all times (ie: up to 4" H_2O below chamber pressure)

3.8 Endurance

The BISS shall be designed to operate in accordance with the criteria herein for a period of not less than 360 (objective 1000 hr) hours of continous trouble free operation without maintenance beyond replacement of filters and other than the suit and tunnel shall be designed for a total operating life of not less than 20,000 hours.

The suit and tunnel of the BISS and all equipment integral thereto shall be capable of withstanding, without violation of any design criteria, 10 cycles each (20 cycles objective) of cleaning of external surfaces, ETO/FREON decontamination, and dry heat sterilization and 90 cycles (180 cycles objective) of cleaning of internal surfaces.

The total life of the BISS suit and tunnel or parts thereof shall be up to 24 months from production to end of life. This total shall be composed of a storage life of up to 12 months and a service life of up to 12 months. Consideration may be given to extension of storage life without exceeding a total life of 24 months.

When either the service life or endurance cycle limits have been reached, the BISS suit and tunnel shall be removed from service.

3.9 Sterile Maintenance

The BISS design shall permit at least one replacement of the tunnel and suit without jeopardizing the sterility of the main chamber.

4.0 Definitions

4.1 BISS - Bio-Isolator Suit System. A system which permits a technician to enter and work in a sterile chamber while being biologically and topologically isolated from the system. The BISS system consists of the equipment defined below.

4.1.1 BISS Suit - (or Suit and Tunnel). The physical envelop which forms the barrier between the technician and the sterile environment of the chamber.

4.1.1.1 Outer Suit - That portion of the BISS Suit which envelops the technician.

a) Suit shell (or outer shell) - That portion of the outer suit which covers the occupants body exclusive of head, feet, and hands.

b) Helmet - That portion of the outer suit which covers the occupant's head.

c) Gloves - That portion of the outer suit which covers the occupant's hands.

d) Boots - That portion of the outer suit which covers the occupant's feet.

4.1.1.2 Tunnel - That portion of the BISS Suit which connects the back of the outer suit to the hatch, and through which the technician enters and leaves the outer suit.

4.1.1.3 Inner Suit - The garment worn by the BISS suit occupant to provide removal of excess body heat. The garment will either be air cooled or water cooled.

4.1.1.4 Personal Under Garments - The garments worn by the BISS suit occupant to separate the surfaces of his body and extremities from the inner surfaces of the outer suit, inner suit, gloves, and boots. These garments will consist of fabric under wear, light weight fabric gloves, socks and/or slippers or shoes. (If a water cooled inner suit is employed, the personal underwear may be incorporated in the inner suit.)

4.1.2 Life Support Subsystem - The equipment of the BISS system which provides and maintains a healthful, comfortable, habitable environment for the technician in the BISS suit.

4.1.2.1 Gas Supply Equipment - That equipment which provides the conditioned breathing (and cooling where applicable) gas to the BISS suit occupant. This includes air conditioning equipment or vortex tubes, distribution hoses, regulators,manifolds, etc. This includes both normal and back-up gas supply and emergency oxygen.

4.1.2.2 Gas Scavenging Equipment - That equipment which provides a power exhaust of the BISS suit to remove expired gas, cooling gas, and gases released by the body of the occupant. This equipment shall, with the gas supply equipment, provide pressure control of the BISS suit.

4.1.2.3 Water Supply Equipment - That equipment which provides thermostatically controlled water to the water cooled under suit (if used).

4.1.3 Hatch - The interface between the tunnel and the sterile chamber wall providing a door for entry to the tunnel.

4.1.4 Communications Subsystem - The equipment and procedures whereby suit occupants communicate with each other and with personnel outside the chamber.

4.1.5 Ancillary Equipment - . Equipment needed to make the BISS a working system but not specifically included in the above categories. Examples are:

- Tunnel support boom
- Tunnel reefing mechanisms and equipment
- Suit donning rack.

4.2 Assembly/Sterilizer (A/S) - A facility for the decontamination and sterilization of a spacecraft with subsequent checkout, assembly, and repair in a sterile environment. The BISS system will be part of the A/S.

APPENDIX B

LEAK DETECTION ANALYSIS

1. Introduction

The objective of this task is to develop concepts based on sensitive leak detection which can be used to infer bio-integrity of the BISS system. The real time or near real time determination of the bio-integrity of the BISS system using microbiological techniques is not considered feasible with existing methods.

2. Analysis

2.1 Basic Relationships

Consider the schematic shown in Figure B1. In this simple model, the volume V represents an arbitrary partial suit volume, bounded by the suit surface S, that is monitored by a simple detector. Q is a constant leak rate into the suit (liters/sec) containing a tracer at concentration C_o (the leak starting at t =0). F (liters/sec) represents the purge flow through the volume C which contains the tracer at concentration C_i while c(t) is the concentration of the tracer exhausting from the volume V at time T. Assuming perfect mixing of streams F and Q in V and no sources or sinks of tracer in V, the differential equation for the concentration C(t) is:

$$\frac{d}{dt} C(t) = \frac{QCo + F\,Ci}{V} - \frac{F + Q}{V} C(t) \qquad \text{(B-1)}$$

The complete solution of this equation is:

$$C(t) = \frac{Q\,C_o + F\,Ci}{F + Q} + \left(C(0) - \frac{Q\,Co + F\,C_i}{F + Q}\right)\exp\left(-\frac{F + Qt}{V}\right) \qquad \text{(B-2)}$$

Where C (0) is the value of C (t) at time zero, and in general is not equal to C_o.

For any practical system it will be true that F is much greater that Q. Thus equation (B-2) can be reduced to:

$$C(t) = \frac{QCo + FCi}{F} + \left(C(0) - \frac{QCo + FCi}{F}\right)\exp\left(-\frac{F}{V}t\right) \qquad \text{(B-3)}$$

Holes less than 0.5 microns in diameter, with a length to diameter ratio greater than 50, are assumed for the sake of this discussion to be impermeable to bacteria. The air flow through a hole of these dimensions with a pressure differential of 0.1 atm across the hole is of the order of 10^{-12} liter/sec. If leak rates of this magnitude are to be detected in reasonable time, a trade-off between V and F has to be made and high sensitivity detectors are required. Note that this ΔP is significantly higher than that expected across the suit but serves well for the sensitivity comparison.

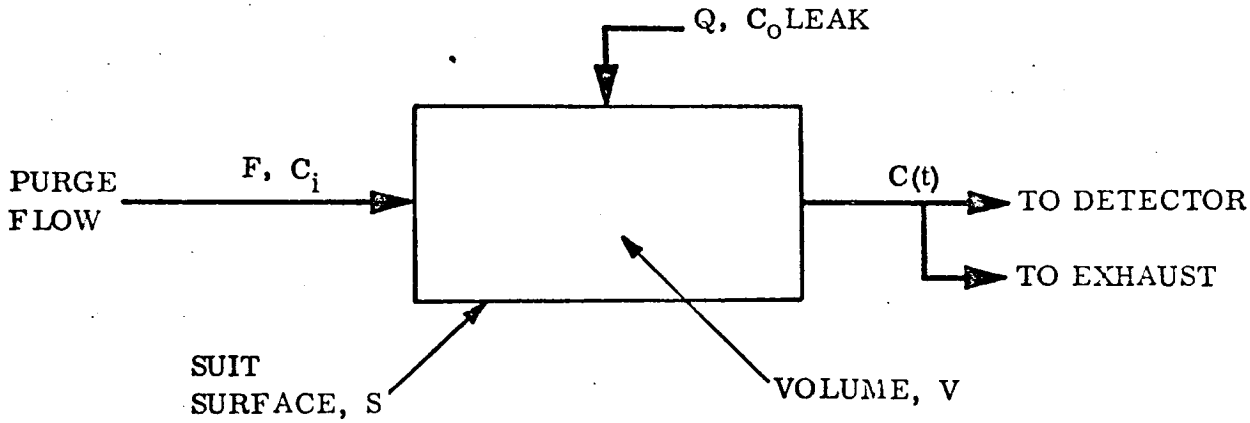


Figure B1. Conceptual System for Evaluating Leak Detection Sensitivity

2.2 Comparison of $C^{14}O_2$ and He Systems

Proper additional approximations to equation (B-3) are of special value in comparing leak detection sensitivities of different techniques.

A. Radioactive Carbon Dioxide

$C^{14}O_2$ is readily detectable at a level of 200 disintegrations per minute (dpm) per liter* and is commercially available at a concentration of 3×10^{12} dpm/liter. For a system using $C^{14}O_2$ the following relationships hold:

$$C(0) = C_i \approx 0 \qquad \text{(B-4)}$$

$$QC_o >> F\,C_i \qquad \text{(B-5)}$$

Thus, for a system using $C^{14}O_2$ equation (B-3) reduces to

$$\frac{C(t)}{C_o} \approx \frac{Q}{F}\left(1-\exp\left(\frac{F}{V}\,t\right)\right) \qquad \text{(B-6)}$$

Using the sensitivity and concentration stated above, it is required that

$$\frac{C(t)}{Co} \approx \frac{2 \times 10^2}{3 \times 10^{12}} = \frac{2}{3} \times 10^{-10} \qquad \text{(B-7)}$$

Taking $Q = 10^{-12}$ liters/sec and arbitrarily assigning $Ft/V > 2$ (such that $\exp(Ft/V) << 1$), equations (B-6) and (B-7) can be solved for a maximum value of F.

$$F \approx Q\,\frac{Co}{C(t)} \approx \frac{3 \times 10^{-12}}{2 \times 10^{-10}} = .015 \text{ liters/sec} \qquad \text{(B-8)}$$

Assuming 1000 seconds required for the concentration of $C^{14}O_2$ to reach the detectable limit, the monitored volume for a single detector is limited to:

$$V < \frac{Ft}{2} = \frac{.015 \times 10^3}{2} = 7.5 \text{ liters} \qquad \text{(B-9)}$$

In this model the detection of leak rates of the order of 10^{-12} liters/sec appears within the state of the art using radioisotopes.

---

* V.P. Quinn and C.D. Wagner, 1959, "A Comparison of Ionization Chambers and Liquid Scintillation Methods for Measurement of Beta Emmitters", Presented at "Symposium on Ionization Chamber Measurements of Radioactivity and Radiation" San Francisco.

B. Helium

The use of a mass spectrometer detecting helium does not compare favorably with radioisotope detection. Helium is normally present in air at about 5ppm. (See Table 3.1 of Appendix A). Assuming a mass spectrometer can dependably sense a concentration change of one per-cent by volume (.05 ppm) and that the helium gas concentration Co is 100%, a relationship equivalent to (B-7) can be developed for helium.

For helium $C(0) = Ci \neq 0$ (B-9)

This relationship reduces equation (B-3) to

$$\frac{C(t) - Ci}{Co} \approx \frac{Q}{F} \left(1-\exp-\left(\frac{F}{V} t\right)\right) \quad \text{(B-10)}$$

This relationship for helium is equivalent to the relationship of equation (B-6) for $C^{14}O_2$. For the concentrations and detection sensitivities stated above.

$$\frac{C(t) - Ci}{Co} = \frac{5 \times 10^{-2} ppm}{10^{6} ppm} = \frac{1}{2} \times 10^{-7} \quad \text{(B-11)}$$

Comparing equations (B-7) and (B-11) it is seen that a helium detecting system, in air, is approximately three orders of magnitude less sensitive that a $C^{14}O_2$ system.

The large volume of the assembly area outside the BISS, along with the cost of tracer gases, probably precludes the use of tracers in any significant concentrations in that volume. Partial or complete compartmentation of the BISS outer suit using double walls to contain the tracer gas would appear promising from a leak detection standpoint. A leak through either wall could be sensed. Another possibility is to direct a jet of tracer gas against the outside suit wall for periodic checking. Aspiration could be used in either case to sample the gas stream with the number of sampling points and detectors determining the effective detection volume V.

Whatever the detection scheme, the determination of the bio-integrity of the BISS system is a basic part of the system and has to be considered throughout the overall course of system design.

APPENDIX C

MATERIAL PROPERTY DATA SHEETS

TABLE C-I

PROPERTIES OF CLEAR CR-39 MONOMER*

PROPERTY	VALUE
Specific gravity	1.31
Hardness, Rockwell M	95-100
Abrasion Resistance, X methacrylate	30-40
Tensile Strength, RT, psi	5000-6000
Flexural Strength, RT, psi	5000-6000
Mod. Elas. in Flexure, RT, psi x 10^5	1.6-2.0
Compressive Strength, psi	22800
Compressive Modulus, psi x 10^5	2.3
Specific Heat, cal/g/^{o}C	0.55
Thermal Expansion, ^{o}C x 10^{-5}	15.3
Thermal Conductivity, BTU/hr/ft^2/in/^{o}F	1.45
Water Absorption, %	0.2-0.4

*References 1,2.

TABLE C-II

PROPERTIES OF LEXAN POLYCARBONATE *

PROPERTY	VALUE
Specific Gravity	1.20
Hardness, Rockwell M	70
Tensile Strength, psi	9500
Tensile Modulus, psi x 10^5	3.45
Compressive Strength, psi	12500
Compressive Modulus, psi x 10^5	3.45
Flexural Strength, psi	13500
Flexural Modulus, psi x 10^5	3.40
Poisson's Ratio	0.37
Modulus of Rigidity, psi x 10^5	1.16
Water Absorption	0.35
Thermal Conductivity, BTU/sec/ft^2/in/^oF	0.02
Thermal Expansion, in/in/^oF x 10^{-5}	3.75
Specific Heat	0.30

* Reference 3

TABLE C-III

PROPERTIES OF "TEFLON" FEP *

PROPERTY	VALUE
Specific Gravity	2.15
Tensile Strength, psi	3000
Ultimate Elongation. %	300
Tensile Modulus, psi x 10^4	7
Folding Endurance (MIT), cycles	4000
Tear Strength, initial (Graves), gm/mil	270
Kinetic Coefficient of Friction	0.57
Water Absorption, %	0.01
Thermal Expansion, in/in/^oF x 10^{-5}	18
Thermal Conductivity, BTU/in/hr/$ft^2/^oF$	1.35
Specific Heat	0.28

* References 4,5

TABLE C-IV

FLAMMABILITY OF PLASTIC MATERIALS

MATERIAL	RATING	REFERENCE
Teflon - TFE	Non-flammable	6,7
Teflon - FEP	Non-flammable	4,5,7
Lexan Polycarbonate	Self Extinguishing	3,7
Armalon	Non-flammable	7,8
Poly (vinyl flouride)	Self Extinguishing	7,9
Kapton Polyimide	Self Extinguishing	7,10
Poly (vinyl chloride)	Self Extinguishing	7
Butyl Rubber	Non-flammable	11

TABLE C-V

WATER VAPOR PERMEABILITY

MATERIAL	VALUE	REFERENCE
Saran Film	0.14 (1)	12
Saran F-220	1.0-1.5 (3)	13
Poly (vinyl chloride)	16. (1)	12
Lexan	14. (2)	3
Teflon FEP	0.40 (3)	4
Poly (vinyl fluoride) Tedlar)	3.24 (3)	9
Polyimide	5.4 (3)	10

Note:

1. cc(STP)/cm^2/mm/sec/cm Hg. x 10^{-8}
2. cm^3/STP/mm/sec/cm^2/cm Hg. x 10^{-13}
3. gm/(100 sq.in.) (24 hrs/mil) ASTM E-96-53T

TABLE C-VI

CARBON DIOXIDE PERMEABILITY

MATERIAL	VALUE	REFERENCE
Saran Film	0.0031 (1)	12
Poly (vinyl chloride)	0.010 (1)	12
Lexan	80.0 (2)	3
Teflon FEP	1670. (3)	4
Poly (vinyl fluoride) (Tedlar)	15. (3)	9
Polyimide	45. (3)	10

Note:

1. cc(STP)/cm^2/mm/sec/cm Hg. x 10^{-8}
2. cm^3/STP/mm/sec/cm^2/cm Hg. x 10^{-10}
3. cc/(100 sq.in) (24 hrs/mil) ASTM D-1434-58

TABLE C-VII

OXYGEN PERMEABILITY

MATERIAL	VALUE	REFERENCE
Saran Film	0.00024 (1)	12
Saran F-220	2. (2)	13
Poly (vinyl chloride)	0.012 (1)	12
Teflon - TFE	0.92 (1)	12
Teflon - FEP	850. (2)	4
Poly (vinyl flouride) (Tedlar)	3. (2)	9
Polyimide	25. (2)	10

Note:

1. cc(STP)/cm^2/mm/sec/cm Hg. x 10^{-8}
2. cc/ (100 sq.in) (24 hrs/mil)

TABLE C-VIII

NITROGEN PERMEABILITY

MATERIAL	VALUE	REFERENCE
Saran Film	0.000056 (1)	12
Poly (vinyl chloride)	0.004 (1)	12
Teflon - TFE	0.28 (1)	12
Teflon - FEP	320. (3)	4
Lexan	3. (2)	3
Poly (vinyl fluoride) (Tedlar)	0.25 (2)	9
Polyimide	6. (2)	10

Note:

1. cc (STP)/cm^2/mm/sec/cm Hg. x 10^{-8}
2. cm^3/STP/mm/sec/cm^2/cm Hg. x 10^{-10}
3. cc/ (100 sq. in) (24 hr/mil

TABLE C-IX

PERMEABILITY RATE

MATERIAL	VALUE	REFERENCE
Teflon - FEP Hydrogen	2200. (1)	12
Poly (vinyl fluoride)(Tedlar) Hydrogen	58.1 (1)	9
Polyimide Hydrogen	250. (1)	10
Helium	415. (1)	10

Note:

1. cc/(100 sq.in) (24hrs/mil)

TABLE C-X

ELECTRICAL PROPERTIES

Material	Reference	Insulation Resistance, megohm mfds.60cps	Dielectric Strength (1 mil), volts	Dielectric Constant 1 KC	Dissipation Factor 1 KC	Volume Resistivity, ohm-cm	Surface Resistivity ohm	Corona Start Voltage, (1mil) volts
Polyimide	10	100,000	7000	3.5	0.003	10^{18}	10^{16}	465
Tedlar	9		4000	7.0	0.085 (1)	$3x10^{13}$	10^{16}	
Teflon - FEP	4		6500	2.0	0.0005 (1)	10^{17}	10^{16}	
Lexan	3		3910 (4)	3.0	0.01 (3)	$2.1x10^{16}$		

Note:

(1) 100 KC

(2) 100 MC

(3) 1 MC

(4) 1.5 mil

REFERENCES FOR MATERIALS PROPERTIES

1. CR-39 Technical Bulletin, Pittsburgh Plate Glass Company
2. Bulletin 51, "Homolite 911 (Cast from CR-39 Monomer) ", The Homolite Corporation
3. Lexan Polycarbonate Sheet, Bulletins E-17, E-18, E-23 to #-26, General Electric
4. Bulletin T-1C, "Teflon FEP Film", DuPont
5. Bulletin T-2B, "Teflon FEP Film", DuPont
6. Bulletin A-9819, "Teflon Tetrafluoroethylene Resin", DuPont
7. Plastics World, Film and Sheeting Chart
8. Industrial Fabrics Bulletin, "Armalon", DuPont
9. Bulletin TD-1B, "Tedlar PVF Film", DuPont
10. Bulletin H-1, "H-Film," DuPont
11. "Protective Coated Fabrics", Cooley, Inc.
12. Plastics Design and Processing, September 1965
13. Saran Product Bulletin, Dow Chemical Company

APPENDIX D

MATERIALS TESTING EQUIPMENT

The following photographs display some of the major items of physical testing equipment in use, or to be used, in Task IV.

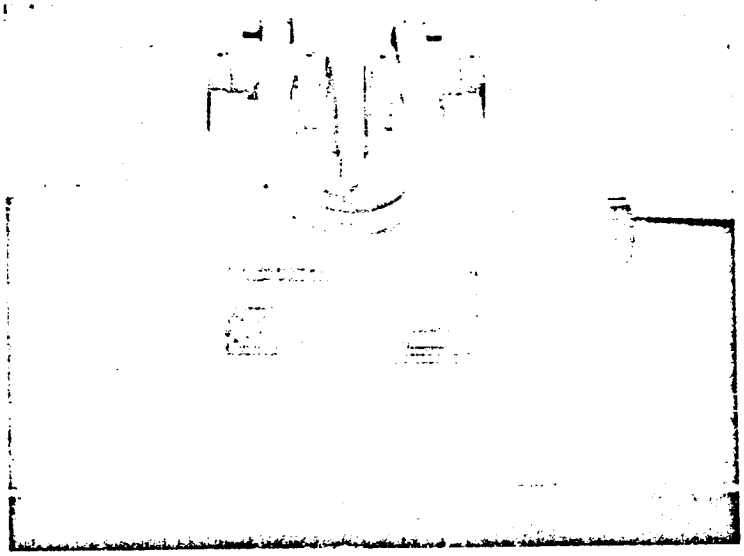


FIGURE D-1 - TABER ABRASER MODEL 174

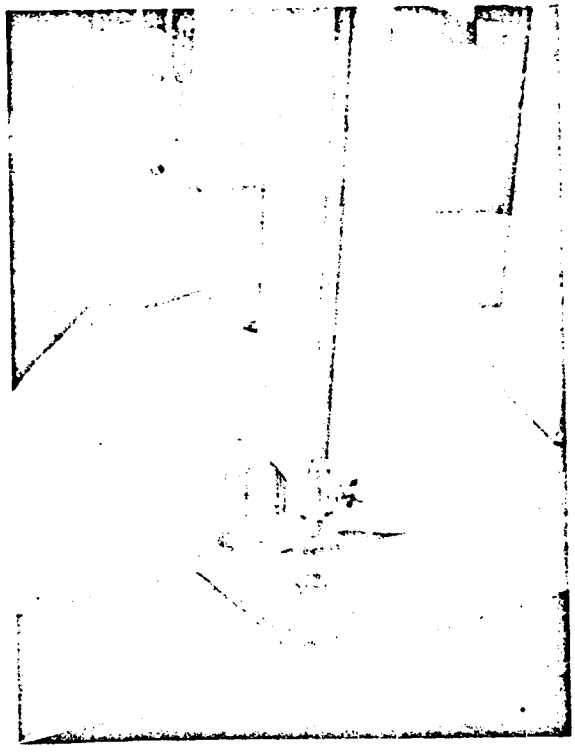


FIGURE D-2 - GARDNER IMPACT TESTER

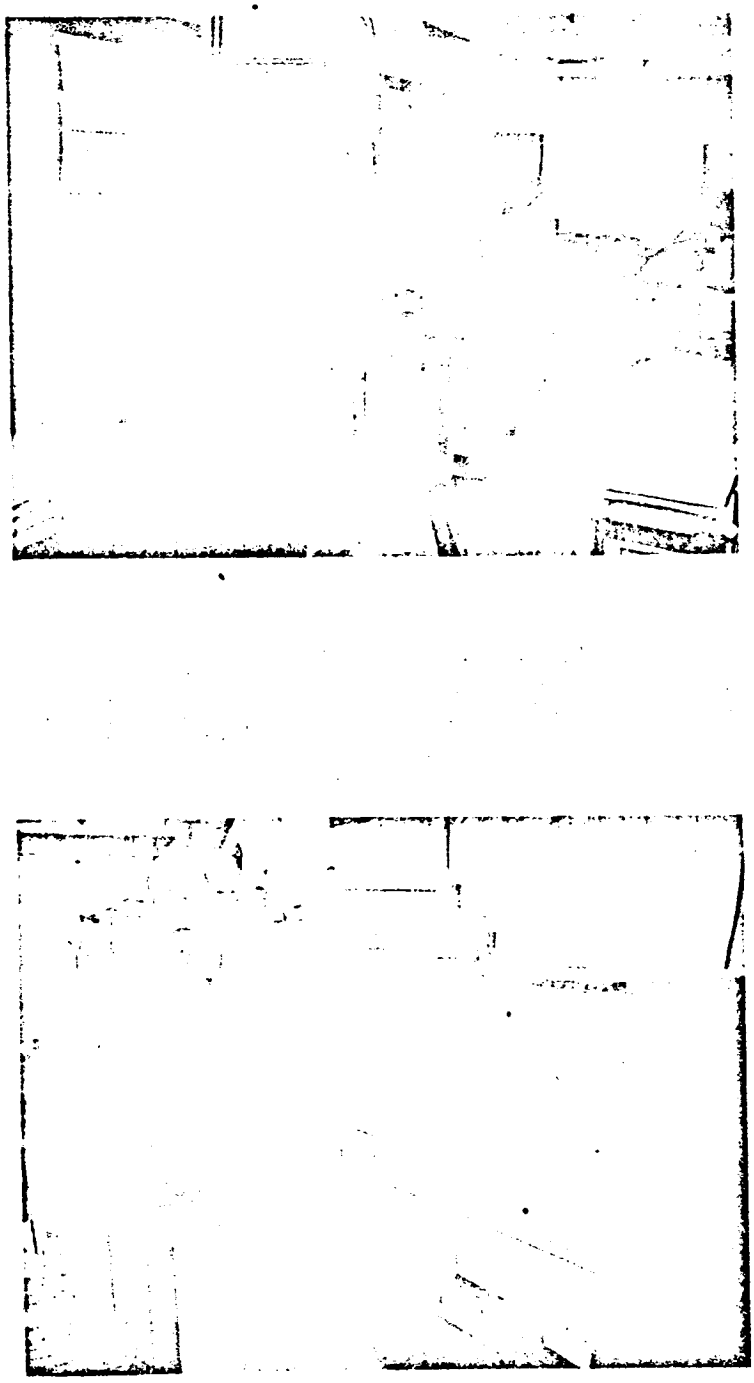


FIGURE D-3 - TEMPERATURE AGING FACILITY

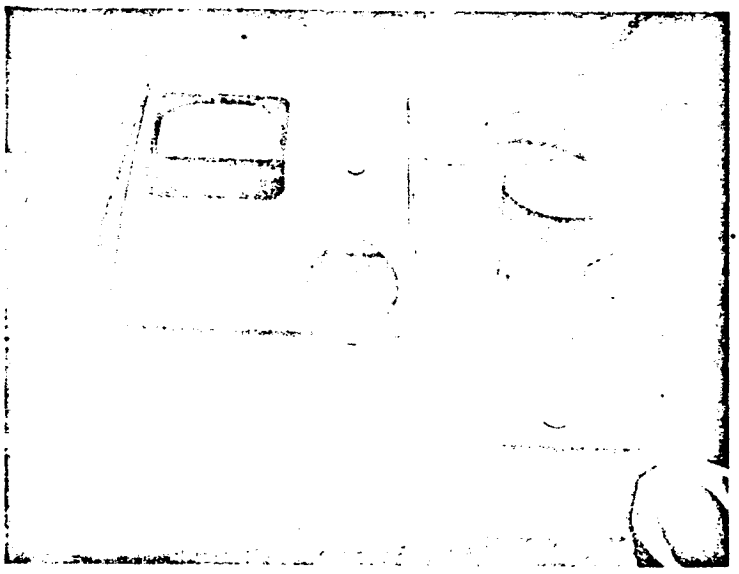


FIGURE D-4 - "COLOR-EYE REFLECTANCE INSTRUMENT

Note: Although use of this instrument is not a portion of the Work Statement or Integrated Test Plan, it may be utilized to assist in assessment of any material color changes as a function of the test environments.

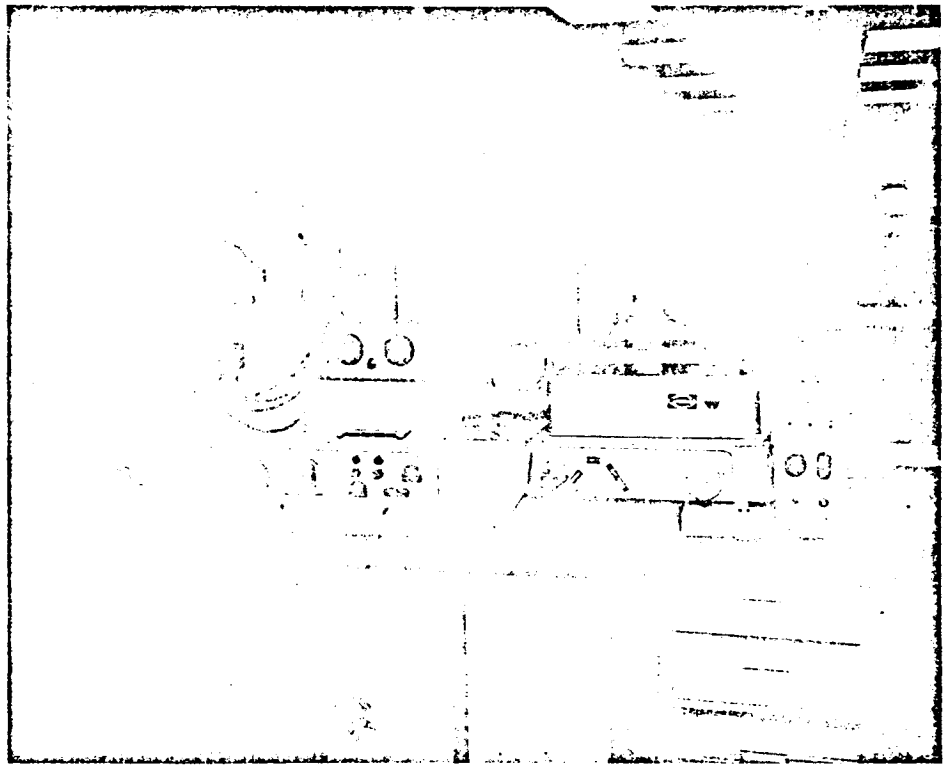


FIGURE D-5 GIER-DUNKEE ABSOLUTE DIRECTIONAL HEATED CAVITY REFLECTOMETER

APPENDIX E

CONSIDERATIONS OF THE HYGIENE ENVIRONMENT OF THE BISS SUIT

1. Background

In the process of its use, the BISS System will be exposed to a variety of microbiological flora native to the individuals in the suit. The use of a chemical means of prophylaxis and disinfection or sanitization of the suit, to protect these individuals from a possible source of infection, is indicated. For the purposes of disinfection, bacteria fall into three categories.

A. Vegetative

Such as the staphlococci, streptococci, and other organisms related to respiratory pathogens.

B. Tubercle Bacilli

Which because of the waxy capsular material surrounding them present a barrier to the access of a disinfecting agent.

C. Spores

By their nature are very resistant to both chemical and heat sterilization. For a disinfectant to function against spores, requires a period of time inconsistent with that allowable between suit changes. Fortunately, the few types likely to be encountered in the suit system can be prevented by prophylactic means from producing any hazard to the suit wearer. Provided prior cleansing is thorough, satisfactory disinfection exclusive of spores normally can be obtained.

2. Methods of Cleansing

The number of materials available for a cleansing operation is numerous. A nonionic detergent would be preferable in that no ionic interference with the disinfectant treatment would occur. The purpose of the detergent is to remove oils and films which could retain microbes and sheild them from the germicide. Among the suitables commercially available detergents in this category are:

- Triton x-100 - Rohm & Haas
- Terfitol NPX - Union Carbide
- Tergitol 15-s-7 - Union Carbide

These should be used in approximately 5% aqueous solutions. Since the physical and chemical properties of these surface active agents are essentially the same, Triton x -100 was selected, primarily on the basis of cost.

3. Methods of Disinfecting

For the purposes of BISS application, the disinfectant used must be tuberculocidal. Since this requirement is much more stringent than that for any vegetative type cells, it follows that if the treatment is tuberculocidal it will be germicidal to any vegetative type cells encountered. The number of materials which can fulfill this criteria is not extensive. They are:

- 70 percent isopropanol
- A solution of 8 percent formaldehyde in 70 percent isopropanol
- A solution of Wescodyne G (an iodine donor) at 450 ppm.

Although there are many commercially available disinfectants most are not recommended for various reasons. For example;

- Cl Donors - A low PH is needed and their use would place a constraint on materials used due to their inherent corrosive activity.
- Br & I_2 - Acute dermal toxicity
- Chlorophenates - Dermal Toxicity
- Metal Salts - Dermal Toxicity
- Sulfur Compounds - Slow acting - toxicity
- Quaternary Ammonium Compounds - Limited Spectrum of activity

The factors influencing the selection of isopropanol are that there will be no residual chemical, it will exhibit a tuberculocidal activity and according to Spaulding is effective against influenza virus, entero viruses, coxsaskie and echo viruses.

Due to the insufficient time between suit changes, this type of treatment was considered inadequate for the treatment of possible spores. For example, the organism causing athletes foot (tricho-phyton) forms a chlamydospore which is a very resistant spore form. In order to insure its destruction the suit would have to be treated a minimum of 3 hours.

The most feasible method of prevention of infection by any organism of this type would be by taking prophylactic measures. Any of the commercial preparations such as "Desenex" or Asterol" should be applied liberally to the socks, feet and shoes if they are used prior to entrance to the suit. Anyone with a ringworm infection

of the hair, skin or nails, which are caused by other members of the dermatophytes, should be barred from use of the suit.

The use of a liquid type of disinfecting agent on the BISS suit itself was considered. But, in view of the problems of maintaining the bio-integrity of the suit, a liquid disinfectant would impose unnecessary hazards. If small micron size holes in the suit material developed during the normal work cycle, any liquid at the site of the holes might permit organism migration through capillary action against the opposing pressure differential, thereby violating the bio-integrity of the suit. The use of a surface active agent for a cleansing operation would, by lowering the surface tension, increase the likelihood of a capillary migration of contaminants.

4. Hygenic Practices to be Employed

A prophylactic measure which will consist of a shower using a "Phisohex" type soap will be mandatory before donning the undergarment. Additionally, personnel should wash their hands with liberal quantities of "Phisohex" type soap immediately prior to entering the suit. This would provide a residual bacterio static deposition on the hands. The use of "undertaker type" white gloves will further protect the worker from possible transfer of infectious microorganisms and may improve the acceptability of the suit to the wearer.

The only area of skin which would be exposed to the surface area of the suit is the head. It will be necessary to disinfect the helmet which is the most potentially hazardous area of contamination.

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